Motion Induced Transformations of Auditory Memory

A thesis submitted in partial fulfilment of
the requirements for the degree of
Master of Arts in Psychology.

by

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CONTENTS

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ABSTRACT

It has been demonstrated that when a rotation of a visual pattern is implied, an observer's memory for the orientation of the pattern tends to be displaced forward in the direction of the implied movement (Freyd & Finke, 1984). This phenomenon has been termed "representation momentum", in analogy to the way a physical object continues along its path of motion through inertia.

In this current research, attempts were made to extend this phenomenon into the auditory domain, by using implied movement of sound rather than vision. The first two experiments adopted the standard procedure, employing three static speakers in the inducing stage, with a probe point on either side. The prediction was, that the probe speaker placed forward in the direction of movement would be more difficult to identify as being "different", because subject's memory had been distorted towards that location. The results however did not support the hypothesis.

The final two experiments were based on the apparent motion procedure adopted by Hubbard & Bharucha (1988). Subjects were asked to listen to a sound progressing in a linear fashion behind a curtain in front of them. When the sound stopped they were asked to indicate the vanishing point. Results showed that subject's perception of the last location of the sound was displaced forward in the direction of the motion, in accord with Freyd's memory displacement hypothesis.

Implications for further research in this area are also discussed in the concluding section.

CHAPTER 1

REVIEW

INTRODUCTION

The importance of the detection of movement for human perception and cognition has been noted by many researchers. Gibson (1979); Johansson (1975); Cutting & Kozlowski (1977), and Lasher (1981) have all shown that the human perceptual system is particularly responsive to changes in the environment. Also, the claim that movement is fundamental to an understanding of the physical world is supported by demonstrations with infants which indicate a crucial role for relative movement in the parsing of the visual scene into coherent and bounded objects (Spelke, 1982; & Spelke, 1983). These experiments noted that information about movement was more important for perceiving object cohesiveness than unity of shape, colour and texture. This has led to the claim that perhaps the perceptual system may be organized for analysing change rather than stasis, and to the extent that dynamic information is important to perception we may expect it also to be important to representation (Freyd, 1983a).

DEVELOPING A THEORY OF DYNAMIC REPRESENTATIONS

Freyd's interest in this area initially grew from questions she had about how people manage to recognize and interpret handwriting when so many styles, and degrees of legibility are encountered daily. The traditional pattern recognition accounts of letter perception i.e. Template Matching and Feature Analysis Theories - refer Anderson, 1990) did not seem to adequately account for this ability because they proposed that readers either recognized given letters by perceiving their "distinctive features", or else they attempted to compare them to various stored patterns. Instead, Freyd proposed that perhaps handwriting recognition makes use of our knowledge about how letters are formed, and that we use this knowledge of drawing method when interpreting static traces. Interestingly, this idea was born out of a personal awareness Freyd gained whilst learning to read and write Japanese characters. She discovered that if she wanted her characters to be easily recognized by native Japanese readers, then following the correct stroke order was of critical importance. An experimental study specifically aimed at investigating her hypothesis (Freyd, 1983a) indeed suggested that knowledge and familiarity with the drawing methods used, aided the recognition of static characters that were distorted in some way. This added credence to a previous study (Zimmer, 1982) which had revealed that people were better able to answer questions about the visual characteristics of a given handwritten letter when they formed a mental image of the letter being drawn rather than just an image of the static letter.

These findings therefore indicated that the process of handwriting recognition can be influenced by tacit knowledge about how letters are formed; and that readers appear capable of using this prior knowledge to help them decipher written text, by forming a dynamic mental image of the letter being drawn. The conclusion then claims that people can perceive dynamic information even when the stimuli being inspected are static. These findings were in contrast with most theories of static form perception at that time (e.g. Kosslyn, 1980) and they created questions pertaining not only to the role that the ability to represent dynamics may play in perceiving things other than letters, but they also raised issues relating to which properties of the mental representation actually become dynamic.

These questions prompted Freyd to begin further investigations into the role that movement may play in aiding our perception in other areas. She surmised, that if it could be shown empirically that the representation of movement occurred under static conditions, then it would indeed suggest that the mental representation of movement is a fundamental organizing principle for human perception.

In the spirit of Shephard's (1984) assertion that "the internalization of the world's regularities will become apparent in situations of incomplete and impoverished input", she proposed that one of the best methods to test the importance of movement perception would be in a case where technically no movement was actually present, but instead was simply implied. In order to explore this premise, Freyd asked subjects to view a series of photographs of natural visual events (e.g. waves crashing, animals moving, a person jumping off a wall) which provided rich cues to convey the inherent movement. Subjects looked at a photograph (presented tachistoscopically) for 250 msec, and after a brief interval (250 msec) their memory for these scenes was tested. They had been instructed only to look for subtle differences between each pair of photographs, but no mention of movement was made. The results, based on reaction time data, clearly indicated that subjects found it more difficult to reject distracters when these were photographs of the same scene shot slightly later in time rather than equally earlier in time (Freyd, 1983b).

It appeared then, that the motion cues in the photographs were in some way capable of inducing a mental representation which captured the movements an observer would experience if he was actually present and observing the scene in person. This compelling mental "visualization" was so effective in capturing the dynamic properties, that it created a problem for memory when subjects were asked to accurately recall what they saw. This apparent dynamic quality associated with imagery was not a new development, since various "transformational" properties of mental images had been well documented as a consequence of the mental rotation research undertaken by Roger Shepard and his colleagues (e.g. Shepard & Metzler, 1971; Shepard & Feng, 1972; Cooper & Podgorny, 1976; Shepard & Cooper, 1982). However, these transformations were described as "processes" which people performed on static representations of an object (Shepard, 1981), therefore the idea of people being able to represent the motion implied in photographs by forming dynamic mental representations, was a rather different assertion.

"REPRESENTATIONAL MOMENTUM"

The photographs in the previous experiments set out to capture naturally occurring scenes depicting "real world" action, in which the motion displayed was strongly implied as well as being both unidirectional and irreversible. Yet, the possibility that subjects could have deduced the motion involved by understanding the meaning implicit in the photograph (i.e. semantic assessment) rather than actually *representing* the dynamic properties inherent in the scene, could not be totally rejected. Therefore Freyd set herself the task of developing a more suitable method of reliably establishing and measuring this effect.

In a subsequent investigation, an attempt was made to measure changes in the mental representation of a visually presented geometric pattern, in which implied reversible motion had been induced by way of a prior sequence of static displays (Freyd & Finke, 1984). The central aim of this research was to demonstrate that mental representations of an object undergoing an implied transformation, are capable of exhibiting an inertial property seemingly analogous to the momentum displayed by the physically moving object. In this experiment a static rectangle was displayed for 250 msec, at three successive orientations, separated temporarily by inter-stimulus intervals (ISIs) of 250 msec to give the impression of *coherent* motion. Each orientation was separated by an equivalent angular distance (approximately 17°) thereby implying a smooth rotation of the rectangle around its central axis, at a constant angular velocity (see Figure 1).

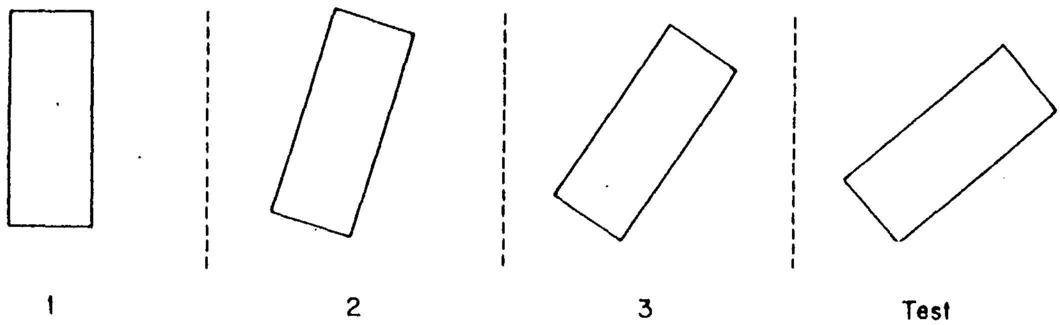

Figure 1: Schematic diagram of a clockwise trial (copied from Kelly & Freyd, 1987, pg 375)

Each experimental trial consisted of a *coherent inducing sequence* made up of three presentations of the rectangle in the manner described above. Subjects were instructed to watch the three presentations (whilst focusing their eyes on a fixation point on the screen to prevent them tracking the motion) and to remember the orientation of the <u>third</u> rectangle. After a retention period of 250 msec, a fourth rectangle *(probe)* was presented. This was either exactly the same as the third presentation (50% of trials), or else very slightly different. This difference manifested itself in one of two ways. In half of the remaining trials, this *probe* represented a slight clockwise rotation of approximately 6°, whilst the remainder of trials displayed an anti-clockwise rotation of exactly the same amount. Subjects were instructed to decide as quickly as possible if the *"probe"* rectangle had the same orientation as the one they had been instructed to remember.

Results indicated that subjects found it much harder to detect any differences in orientation between the probe and the third rectangle in the inducing set, when the probe followed the direction of the implied motion. In this experiment, subjects took on average 216 msec longer and made almost 7 times as many errors, rejecting the forwardly rotated probes compared with the backwardly rotated ones. It was conjectured that subjects were less likely to reject the forwardly displaced orientation, because this position was most similar to their actual memory of the orientation of the final stimulus in the inducing set. However, when the ordering of the first two orientations was reversed so that the impression of a consistent path of motion was no longer created *(incoherent sequence);* the difference between the forward and backward probes was no longer apparent. This result shows that a consistent path of rotation, implying continuous movement, is required to produce the memory displacement effect.

The same outcome was produced (although in less pronounced terms) when the temporal spacing between the inducing stimuli was doubled to 500 msec. At these longer intervals it was considered highly unlikely that any perception of "apparent motion" was occurring. Therefore, the subjective experience of "seeing" movement must have been a cognitive process rather than a perceptual illusion of movement per se. A conclusion that this memory distortion appeared to be independent of elementary sensory processing was therefore postulated, based on the assumption that a cognitively based influence was causing the memory for an object's final position to change along its implicit path of motion. The term "Representational Momentum" was introduced to describe this memory displacement effect. This name was in reference to the apparent inertial property that seemingly becomes associated with this mental process.

This experimental design came to be viewed as the standard procedure for demonstrating representational momentum effects, and the memory displacement effects proved to be easily replicated and very robust. The memory distortions were observed in virtually all the research participants, and they persisted even when repeated error feedback was given during practice trials and the final orientation in the inducing sequence was the same for all trials (Finke & Freyd, 1985 ; Freyd, 1987) . This weakens any argument suggesting that the observed "over-shoot" occurred because people had trouble either stopping the forward motion or else mentally registering the fact that it had stopped. This is due to the fact that there was no uncertainty about where the object would stop on each trial because the same end point was used each time. Furthermore, any claim that this pattern of results may reflect a natural tendency to extrapolate forward movement per se can also be rejected because a slight change to the procedure was introduced to specifically assess this factor . Freyd & Finke, 1984 ; Finke & Freyd, 1985 ; and Finke & Shyi, 1988 , gave subjects explicit instructions to extrapolate the implied motion to what was considered to be the next step in the sequence. Subjects were very accurate at performing this task, and there was no tendency towards over-estimating the distance the object was expected to travel. This control condition also provided evidence to negate any claims that subjects in the memory task could have mistakenly treated it as an extrapolation task.

A variant of the basic "same-different" method in which a greater number of probe positions were employed, subsequently provided a more sensitive method of measuring the size of the memory displacement effect (Freyd & Finke, 1985). This more sophisticated method used nine closely positioned probes that were presented equally often. This had the major advantage of enabling quadratic regressions to be carried out on the data, thus providing a reliable estimate of exactly how far the memories for the final pattern had shifted forward. Results obtained using this new measurement method, clearly identified a basically symmetrical distribution of "same" responses, with the apex of the curve centred slightly in advance of "true same". That is, subjects responded "same" <u>most often</u> to the orientation that was just slightly forward of the one that was actually correct. This forward shift was calculated to be approximately 10-12% of the distance between the final position in the inducing sequence and what would have been the next step in a continuing progression (Finke et al 1986). This led to the prediction that in any future studies, a test pattern shifted forward by approximately 1/10 of the fully extrapolated distance would be accepted as the remembered pattern most often, and most rapidly by the subject. In cases where this position is correctly rejected, subjects should then take a significantly greater time to register their decision.

All the memory distortions noted in the previous studies occurred in the direction of the implied motion, and this led Freyd and colleagues to theorize that when a person perceives an object as moving (whether the motion be real or implied), inherent in the perception is the fact that the object will continue its forward motion in the immediate future. The theory claims that this forward momentum cannot be instantly halted, and instead a viewer must deliberately attempt to stop it. This results in the implied motion continuing for some distance beyond the point at which this cognitive "stopping signal" was first applied. This has the effect of creating a small forward shift in memory for an object's last observed position. The term "representational momentum" was thus an analogy to the tendency for a physically moving object to continue along its path of motion after attempts to halt the movement have been initiated.

EXTENSIONS OF THE PHENOMENON

In later experiments Freyd and her colleagues sought to determine the range of conditions that must be present in order to reliably predict the momentum effect, and at the same time they attempted to establish if the phenomenon could be extended to other types of implied motion.

An initial task was to determine if it is the representation of a particular object that becomes distorted, or whether it is the representation of an abstract spatial position that is transformed. The latter case seemed an unlikely proposition since the earlier mental rotation studies had already shown that in those tasks, subjects were imagining the rotation of a concrete object or pattern, rather than just an abstract frame of reference pertaining to a particular orientation (Cooper & Shepard, 1973; 1975 cited in Finke, 1989). In an attempt to ascertain object identity requirements with representational momentum, study participants were presented with objects differing in shape and texture (Kelly & Freyd, 1987). When figures with radically differing shapes were presented within a sequence, with the change attempting to imply a rotation of these figures (Exp.2), no forward distortions in the subjects' memories were noted. Under these conditions it was assumed that subjects just observed separate objects at differing orientations, without actually perceiving any movement. However, when a figure retained the same basic shape but instead had its dimensions altered in a minor way (Exp.3 & Exp.5) the memory distortions again became apparent. It was suggested that in this case the overall figure stayed similar enough for the visual system to conclude that it was the same object at differing orientations (Exp.3) or locations (Exp.5). Similarly, when the internal markings of an object were manipulated while the outline of the shape remained unchanged, thereby giving the impression of textural change (Exp.4), a memory displacement was again noted. In this case it would appear that the internal changes that were introduced were not enough to break down the object centred requirement. It is important to note however that the memory distortions found in the above manipulations were by no means as large as would normally be anticipated.

From these studies it seemed reasonable to conclude that for representational momentum to occur at all, some level of object identity must be achieved. An observance of a correspondence between the basic contour of the objects presented to them, appeared to be the main criteria used by the subjects in making this assumption. This notion is in accordance with Shepard's (1984) observations resulting from apparent motion studies, in which he concluded that the visual system prefers transformations that preserve the rigidity of an object. It would appear then that the memory distortions noted in the above experiments resulted from subjects visualizing a particular object as moving rather than perceiving some generalized shapes merely shifting in orientation or location.

It is important to note here however, that this "object centred" requirement took on a new complexity when representational momentum was reported in relation to a tonal sequence which implied a movement along the pitch scale (Kelly & Freyd, 1987; Freyd, Kelly & DeKay, 1990). These studies employed a procedure that was identical to previous studies except that the inducing sequence consisted of computer generated tones of differing frequencies. This provided the impression of a tone rising and falling in pitch. The results produced the typical momentum effects in regard to both error rate and reaction times, and in doing so, showed that the phenomenon is not specifically tied to the visual domain.

While it is rather more difficult to think of a tone as conforming to the traditional criteria used in the visual sphere to specify an object, it must be noted that we normally have little trouble determining either where a sound comes from, or which object it is associated with. This must be accomplished by identifying the various physical attributes of the sound source and linking them together in some cohesive manner to either relate them to a particular object or localize them in space. While there is scant evidence about auditory imagery in the literature, investigators have so far assumed that auditory imagery will be related to audition in much the same way that visual imagery is to vision (Intons-Peterson, 1992). Since two central determinants of auditory experience are Loudness (intensity) and Pitch (frequency), it is assumed that these will also make a major contribution to auditory imagery as well as to our perception of auditory "objects" generally.

Freyd nevertheless reached the conclusion that Representational Momentum appears to be a general phenomenon that is not limited to vision or to implied movement of rigid objects. Instead she stated "I would expect to find Representational Momentum for any dimension of continuous change - but not discontinuous change - that can be mentally extrapolated" (Freyd, 1987, p.435). It is therefore expected that memory displacement effects could be quite widespread.

Two studies (Finke & Freyd, 1985; Finke, Shyi and Freyd, 1986) provided evidence in support of this claim by showing that the momentum effect also occurred when the implied motions of individual parts of a more complex pattern were moved in consistent, yet separate, directions. In these studies, the first three patterns in the inducing sequence depicted independence motions of dots from one of two starting configurations. (Refer Figure 2.)

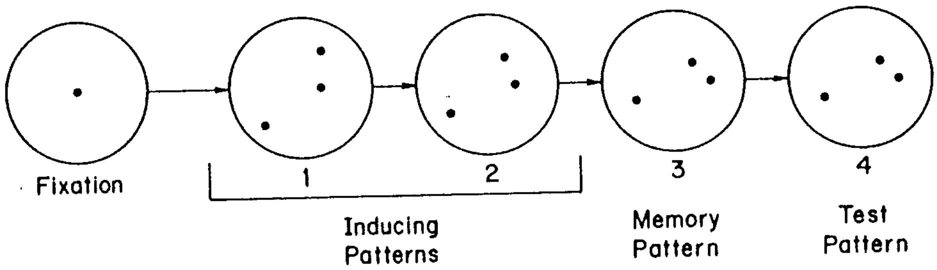

Figure 2. Example of display sequences used in practice and experimental trials. [Following a fixation display, the 4-dot patterns were presented for 250 ms each, separated by ISIs ranging from 250 to 1,000 ms. The subject's task was to remember the third pattern in the sequence (the *memory* pattern), and to judge whether or not the *test* pattern was identical to it in all respects. The first two patterns in the sequence (the *inducing* patterns) depicted independent translations of the dots. The particular inducing patterns shown were presented to half of the subjects, whereas a different set of patterns, depicting opposite motions of the dots, were presented to the other half. The test pattern in this example is identical to the memory pattern; this occurred on half of the trials. For purposes of illustration, the dots are drawn at a larger size, and within a smaller viewing field than in the actual displays (see text).] Copied from Finke + Freyd, 1985 pg 782.

Here the participants were instructed to watch each of the four dot patterns in sequence whilst keeping their eyes fixed on the centre of the screen. Emphasis was placed on the fact that they must watch all three dots at once, as opposed to just trying to track one. Again, error rates and reaction times for rejecting the probe pattern were substantially higher in cases where the pattern was displaced slightly forward in the direction of the implied motion.

These studies were also important in helping to rule out the possibility that the memory distortions found in the rectangle orientation studies, may have been caused by subjects visually "tracking" a rigid object perceived to be moving at a constant rate and in a fixed direction. This is not possible in the more complex array where individual dots simultaneously move in different directions. It is still possible however, that subjects may have intentionally chosen not to heed the instructions and instead just watched the displacement of a single dot in the pattern.

FREYD'S THEORY OF DYNAMIC REPRESENTATIONS

It has previously been reported (e.g. Gibson, 1966; Johanssen, 1976) that humans appear to be extremely well adapted for perceiving and analysing motion and change when they are presented with dynamic stimuli. However Freyd's theory of dynamic representation goes beyond an ability to perceive events which change over time as it also embodies the notion of perceiving dynamic information even when the stimuli being viewed are static. Freyd contends that the demonstrations showing dynamic information to be relevant where it was previously thought mainly static information was used, may in fact, indicate that dynamic information could be primary to the perceptual system.

The formulation of her theory grew initially from her observation that people appear capable of forming a mental image of the motion inherent in a photograph, as has been outlined in an earlier section of this review (Freyd, 1983b). A seemingly related ability had previously been alluded to by Arnheim, 1972, 1974 (cited in Freyd, 1987 & 1992) when he affirmed that a key component of static art appreciation appears to be the excitement generated by the implied dynamics of the art form. This position gained further impetus when empirical evidence was provided to show that even the perception of completely static objects can involve a representation of the underlying forces inherent in the display (Freyd, Pantzer & Cheng, 1988).

Prior to this, most of the imagery research had been concerned with the characteristics of our mental representations (i.e. what information is represented and how this information is encoded). This led to the much published debates in the cognitive literature between those who argued that we code things abstractly, and those who maintained we use encoding principles that are analogous to the ways in which things could be part of a real world event (i.e. Imagery versus Propositional theorists - see Finke, 1989 for a recent review). Following this, a good deal of work was directed towards the study of the transformational properties of the images (e.g. Shepard & colleagues mental rotation studies), which led to the conclusion that when people perform a mental transformation on an object, they appear to engage in processes that are functionally similar to those they use when presented with a physical object. These results also identified the fact that imagery can be a dynamic process, because their subjects showed that they were capable of mentally visualizing and operating on various objects and events. However it is important to note, that at this stage, the representations themselves were *not* seen to possess any dynamic qualities. Instead it was proposed that we engage in mental "processes" (Shepard, 1981) that act on the images and transform them in our minds.

At this time the standard idea of a mental representation was that of a "mental thing" or "data structure" (see

Anderson, 1990) and most of the research to date had concerned itself with the types of mental processes that could be performed on these images. This tends to force a notion of a representation that is implicitly static. Freyd's work however has altered this view by showing that the images themselves must become dynamic to enable people to capture and represent the motion that is inherent in them. In most of Freyd's studies there has clearly been no sensory basis for the detection of the dynamic information, therefore it cannot be said to be a perceptual illusion (as is the case with "apparent motion" or in some cases of implied motion, where motion detectors become "fooled" into thinking something is moving). Since subjects have managed to abstract the motion from the implied sequences of static displays, the perception of the movement cannot be direct. Consequently, the subjects must have made inferences from what they saw (cf. Shepard, 1984; 1987) and formed some kind of cognitive representation on this basis.

Freyd's view of dynamic representation is also different from previous notions of representation, in that **time** is said to be an inherent quality (Freyd, 1987; 1992). Previously it had been assumed that any temporal effects associated with mental transformations (e.g. rotation or scanning rates) had resulted from constraints on our ability to process the spatial information inherent in the image. However Freyd claims that when a mental representation is actively invoked in working memory, the temporal dimension is represented "analogically" (i.e. much as it is in the real world) therefore the temporal changes directly reflect what occurs naturally. Freyd in fact maintains that in dynamic representations **"time represents time"** (Freyd, 1992).

If this is an accurate assertion, the temporal component must be shown to be unidirectional (i.e time in the real world goes forward), and it must be continuous (i.e. between any two points of time another point of time exists). Evidence to substantiate this claim was provided using the representational momentum paradigm, when it was shown that the motion attached to the representation of an object is always extrapolated forward into the future and this movement seems to be represented in a continuous fashion. When subject's memories were probed at a variety of retention intervals ranging from 10 to 90 msecs, their memory shifts were shown to increase in a linear fashion, with predictable minute increases being recorded between each small retention time period (Freyd & Johnson, 1987).

These empirical findings also had important implications for theories of how memories change. Firstly they showed that movement can influence how we perceive and remember things even when the movement information is only implied or simply inferred. In these cases the people were highly motivated not to allow their memories to be altered in any way because the task required them to be very exact in their recall of the final position. Therefore it is highly probable that in certain natural everyday situations, where the motivation to be accurate is not so strong, memory impairments could well be more pronounced.

These memory distortions have also been shown to occur very rapidly (i.e. retention intervals as low as 30 msec have produced the desired effects (Freyd & Johnson, 1987), thereby indicating that the mechanism underlying the memory displacement effect is in the domain of "working memory". This was a significant finding, because up until that time, memory research had been mainly concerned with how visual memories stored in "long term memory" could be distorted following either long term retention (e.g. Bartlett, 1932; Tversky, 1981 or Goldmeir, 1982), or as a result of biasing information presented prior to retrieval (Loftus, 1975; Loftus, Miller & Burns, 1978; McCloskey & Zaragosa, 1985).

RELATIONSHIP BETWEEN REPRESENTATIONAL AND PHYSICAL PROCESSES

While Freyd and colleagues initially used the proposed correspondence between physical momentum and representational momentum only as an analogy to describe the way mental extrapolations were stopped (Finke & Freyd, & Shyi, 1986), they later extended this analogy to embody the notion that the two processes were in fact very similar. This viewpoint appears to have as its roots, Shepard's (1981, 1984) speculation that the most enduring characteristics of the environment have been internalized into our perceptual system during the course of our evolutionary history. This theoretical stance arguing for an analogy between mental transformations and their external states is not new, as this position has received extensive coverage in the congitive literature over the years.

There has been much empirical support for this perspective from both the mental rotation studies (e.g. Cooper, 1976; Shepard & Chipman, 1976) and imagery scanning experiments (e.g. Kosslyn, Ball & Reisser, 1978). The mental rotation research indicated that transformations of imagined objects exhibit dynamic characteristics similar to those of their physical counterparts, and that the mental processing is carried out in a holistic and continuous manner. The imagery scanning experiments on the other hand discovered (from studies requiring imaginary scanning of objects, or the use of cognitive maps in spatial navigational tasks), that as a rule, the spatial relations among objects are preserved in images.

These findings prompted Finke (cited in Finke, 1989) to make a general proposal about the relationship between imaginal transformations and their physical counterparts, which he termed the "principle of transformational equivalence". This made a claim that imagined and physical transformations exhibit similar dynamic characteristics, with each being controlled by the same laws of motion. If the mental and physical processes are analogous, it would be expected that both would follow the same regularities; and the factors that influence one, should also be shown to affect the other. The aim of Freyd's subsequent empirical work therefore was to explore this hypothesis by examining the extent to which the internal properties of physical motion were able to successfully predict aspects of their representational counterparts.

Since physical momentum is proportional to velocity, one would predict greater memory shifts to occur with increased implied velocity. This prediction was successfully borne out with the demonstration that representational distortions increased linearly with implied velocity (Freyd & Finke, 1985), thereby signifying that the strength of the extrapolation tendency is determined by the momentum associated with the implied motion. This velocity dependence of the memory shift was later extended to situations where the inducing sequence implied a consistent change in velocity (Finke, Freyd & Shyi, 1986). In these investigations, subjects were shown sequences which implied that an object was moving either at a constant velocity, a constant acceleration, or a constant deceleration, but where the average implied velocity remained the same. This manipulation of the acceleration was achieved by varying the inter-stimulus interval (ISI) between the items in an inducing sequence. For example, a long ISI between the 1st-2nd display and a short ISI between the 3rd-4th display represented an acceleration while the opposite pattern was consistent with deceleration. As would be predicted from the principles of physical momentum, the resultant memory shifts were shown to be determined by the final implied velocity rather than the average velocity within the sequence. Furthermore, it was shown that when the inducing sequence implied a deceleration to a final predicted velocity of zero, the memory shift was eliminated.

When these findings were incorporated with additional empirical data which indicated that the internal rates at which transformations were performed in representational momentum studies, closely approximated the external rates of physical momentum (Freyd & Johnson, 1987), it seemed that many of the quantitative aspects of the momentum effect coincided quite closely with expectations based on the physical model. These correspondences presented a persuasive argument in favour of the notion that at least some aspects of the inertial properties of motion have been incorporated into mental events. Of even greater interest though, was the fact that subjects in the above experiments showed memory distortions that were determined by the implied changes of acceleration within a display, as this suggested that the subjects were sensitive to the magnitude of the forces inherent in the sequence. This led Freyd to speculate that we may have an underlying representation of physical forces incorporated into our perceptual system (cf. Shepard, 1984; 1987).

An important study which has been interpreted as evidence for this argument is that of Freyd, Pantzer & Cheng (1988). Here it was claimed that subjects exhibited memory distortions which were said to be indicative of their ability to represent the underlying forces held in equilibrium, in a static display. In the first of these experiments subjects were shown a drawing of two objects, one supporting the other (e.g. a plant sitting on a plant stand). These were displayed next to a larger object (a window) which provided a spatial framework. The task required subjects to remember the plant's position. After a short interval a drawing of the previously supported object (i.e. plant) was shown beside the window in exactly the same position as before, but without the supporting surface. In this case the plant was in a state where the forces were now in disequilibrium. Finally, a probe display, showing the plant adjacent to the window at either the same vertical position as before or else slightly above or below its initial position, was presented. Subjects were then asked to indicate if they thought the plant was in the same or different position to that of the original display (see Fig.3).

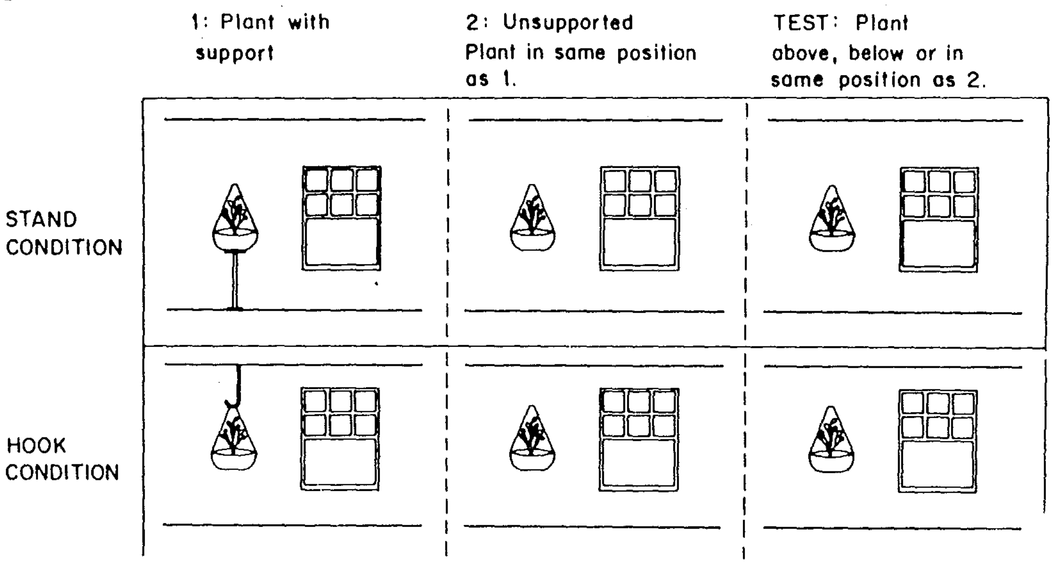

Figure 3. Schematic depiction of the stimuli used in Experiment 1. The first row shows the three displays used in a trial beginning with the table as a support object and ending with the test display showing the plant in the original position. The second row shows a comparable trial for the hook condition. Timing of displays and intervals is indicated at the bottom of the figure.
Copied from Freyd, Pantzer + Cheng, 1988 pg 397.

It was determined that subjects would respond "same" most often for probes depicting the plant slightly below its original location. That of course is the direction it would have moved in real life had the support been removed. In a control condition it was discovered that no memory displacement occurred when the plant was initially displayed without support. Freyd's analysis is further strengthened with the work of Hubbard & Bharucha (1988), who, by using an apparent motion paradigm to test for memory distortions similar to those found by Freyd and colleagues, noted that the magnitude of the memory displacements relating to the vanishing point of a target travelling at a uniform velocity in a linear fashion, was influenced by the direction of the motion. They discovered a consistently greater **downward** displacement for horizontal motion, and a greater displacement for vertical top-to bottom motion than for upwards movement. These findings suggested to them the possibility of an internalization of a downward gravitational influence.

An extension of work in this area has also revealed that the representation of forces can involve cases that are more complex than simple conditions involving only gravity. Freyd et al. 1988 also showed subjects drawings depicting a coiled spring which was either shown alone, or with a box resting on top of it. Memory for the level of compression of this spring was tested by either adding or removing the box from the drawing. It was predicted that subjects would display an upward shift in one memory condition (i.e. decompression of spring) and a downward shift in the other (i.e. compression condition). The results successfully indicated that memory for observed compression was distorted in the predictable direction, given the disruption to the spring's equilibrium by the implied addition or removal of a weighted object.

The studies cited in this section provide strong evidence in support of the notion that the observed memory distortions are attributable to mental representations which are rich analogues of actual physical processes. In these studies, factors that are known to affect physical momentum (i.e.

changes in acceleration; the final velocity of an object; and gravitational influences) have also been shown to relate to the magnitude of representational momentum, as measured by the degree of distortion in a subject's memory for the final position of an object. The only factor that has not yet been studied empirically is the relationship between an object's mass and the influence this has on representational momentum. If the relationship holds as hypothesized, it would be predicted that memory displacements should also become apparent when objects of obviously differing size and weights are presented in salient situations.

Freyd (refer Freyd, 1987; Kelly & Freyd, 1987; Freyd, Pantzer & Cheng, 1988; Freyd, 1992) has repeatedly claimed that the observed effects are the result of encapsulated informational processing - specifically perceptual modularity (cf. Fodor, 1983). This modularity thesis assumes that knowledge is embedded in the perceptual/representational system, and that perceptual analysis is completely self-contained and therefore isolated from our beliefs and expectations in the Semantic/Conceptual system. It is however important to note that this claim is at variance with earlier findings by McCloskey et al. (1980, 1983) who presented results revealing that people display misconceptions about inertia. McCloskey's findings appear contrary to the view that we have accurately internalized the laws governing physical motion. Questions pertaining to the analogue nature of representational momentum will be addressed more fully in the following section.

PROBLEMS POSED FOR THE PROPOSED ANALOG BETWEEN PHYSICAL AND REPRESENTATIONAL STATES

The fact that representational momentum and the accompanying forward memory shifts have been obtained in areas where there appears to be no single analog to the motion of physical objects, appears a little problematic for Freyd's theory, as its central tenet is the analogy to an object being stopped in the physical world.

Firstly, it has been observed that various quadrilateral figures which implied a change in size and shape in the inducing stage, also elicited memory distortions similar to those found for rotations and translations which more specifically suggested motion (Kelly & Freyd, 1987). While changes in shape and size are not generally thought to be governed by laws of motion it was postulated that in the latter case the findings could represent an abstract relationship with physical movement because all the subjects in this experiment made a subjective report of experiencing "motion in depth". This arose because the displays changing in size in a regular manner gave the impression of an object advancing toward them or conversely retreating back into the distance. One interesting finding from this particular set of experiments, stemmed from the observation that when a sequence of rectangles was shown to become more square-like in appearance, resulting in the final memory figure being a perfect square, no memory distortion was evident at all. The reason for this cannot be fully ascertained as there are two possible explanations. Firstly, subjects may have identified the fact that the shape was a square and therefore encoded the semantic category. This information could have taken precedence over any spatial changes thereby effectively halting or over-riding the usual internal transformations. If this was the case, it would be very detrimental to Freyd's modularity theory as a conceptual influence would seem to have penetrated the task. However, another possibility is that in this case, unlike the others, the transformation involved a complete change in the dimension of the object (i.e. both the width and length were altered). This may have been too complex for the visual system to deal with, or it may simply not be indicative of a usual transformation of an object.

More significant however was the discovery that changes in the pitch of a tone were also noted to produce representational momentum, along with the predicted forward memory shifts and the previously identified acceleration and velocity effects. This appears to raise some genuine challenges for the analog proposition, since changes in pitch do not typically specify a change in the position of a sounding object.

While a detailed analysis of the correlation between pitch and motion has, to my knowledge, not been undertaken, there are those who have argued for a relationship. Finke & Shepard, 1986; (cited by Intons-Peterson, 1992) maintain that in the auditory domain the thing that is most analogous to the perception of visual objects is the perception of "auditory objects in pitch space". Pitch space is viewed as a complex medium within which auditory objects (e.g. tones, voices, chords, environmental sounds) can be rigidly transformed while preserving their structure. As a consequence, it has been claimed that many of the musically most significant transformations, including shifts up and down the scale, correspond to rotations in this space.

Finke & Freyd (1988) also noted that memory shifts were larger when the direction of the mental extrapolation was always the same on every trial than when it varied unpredictably from trial to trial. Similarly, Hubbard & Bharucha (1988) and Hubbard (1990) discovered that when the transformation is subjectively continuous, the memory displacements are especially pronounced. It has also been reported that by increasing the number of inducing stimuli from three to four, one can increase the level of memory displacement (Freyd & Johnson, 1987). Physical momentum of course does not depend on the familiarity of an object or how consistently a particular motion has been repeated in the past.

For a strict analogy to physical momentum to hold it would be necessary for the memory distortions to always occur in the direction of the motion of the inducing sequence. The continuity of the change has always implied that it can be extrapolated in the direction of the movement, and the rate at which this occurs will correspond to that of the inducing sequence. More recent experimental work has, however, begun to cast doubt on this claim. Firstly, Hubbard & Bharucha (1988) uncovered an unequivocal cognitive effect which influenced the extent of the exhibited memory distortions. These researchers used a radically different experimental paradigm to assess the level of memory displacement following the abrupt disappearance of a rapidly moving target. Subjects were required to observe a small dot travelling across a computer screen before it suddenly disappeared. They were then requested to pinpoint the exact position the dot had disappeared by operating the computer mouse and placing the cursor over the point of disappearance. The results indicated that when the target travelled in a uniform direction and at a constant speed, then memory displacements similar to those found by Freyd and colleagues were noted. However, when the inducing sequence was altered slightly to give the impression that the target either collided with a frame or was about to bang into it at the time it vanished, the memory distortions were observed to be in the anticipated direction based on knowledge of what was likely to occur after impact.

These results consequently exhibited a negative memory shift by Freyd's standards because the distortions moved in the direction opposite to that of the current path of the motion. However it was evident that there still seemed to be a striking tendency for subjects to mentally extrapolate the motion into the future as Freyd and colleagues had previously contended, although in this case the extrapolation process appeared to be calculated on the basis of what one would expect to occur given the change of circumstances. It becomes apparent then, that rather than being a simple extrapolation of the motion as previously thought, a higher level cognitive influence appears to respond to foreseen changes in the target's behaviour and the memory is displaced in the direction related to this anticipatory process.

While Hubbard & Bharucha concluded that their "memory displacement effect" was equivalent to the representational momentum phenomenon discovered by Freyd et al, their claim is subject to criticism for a number of reasons. Firstly, they used an apparent motion paradigm to induce the effect, whereby subjects were likely to experience the sensory effects of motion, rather than forming a representation of discrete memory patterns. Secondly, these researchers did not include a control condition to determine how subjects would extrapolate the motion in the experiments which saw the target bounce within the confines of the frame (Exps. 4 & 5). In these situations, subjects should have been asked to indicate where they felt the target would go, under each of the three conditions (i.e. pre-collision, collision and post-collision). In this way, it would have been possible to determine if their memory for the vanishing point was displaced along the same representational pathway as that used to extrapolate the motion. Finke & Shyi (1988) have argued that this is important to their theory, since the memory shifts are supposed to occur along the same representational pathways used in mental extrapolation.

Finally, Hubbard & Bharucha's claim that their paradigm is equivalent to a variant of the Representation Momentum paradigm is open to dispute, because the interval between disappearance of the target and indication of the vanishing point, was at least 2 seconds or greater. The observation of a considerable positive memory shift is in opposition to the findings of Freyd & Johnson (1987), who would predict negative shifts with such a long retention interval.

To overcome such criticism, two subsequent researchers (Verfaillie & d'Ydewalle, 1990) decided to reinstate the standard momentum inducing sequence and procedure in an attempt to further investigate this "anticipatory hypothesis" alluded to by Hubbard and Bharucha.

In their experimental strategy, subjects were shown two display sequences. In the first condition, the standard representational momentum inducing sequence showing the implied rotation of a rectangle at three separate orientations around a path of rotation was presented (e.g. Freyd & Finke, 1984). The results obtained from this part of the study were then compared with a second condition in which the same inducing sequence as above was preceded by six other images, to give the impression of it being part of a more complex event. In this latter case, the rotation direction changed periodically in a predictable manner, and the sequence was organized in such a way as to imply a change of direction opposite to that of the local motion path at the time the memory pattern was presented. It was argued that if the momentum effect only involves an extrapolation of the local style of change, then the memory shift should be the same for both conditions because the three images prior to the test pattern presentation were the same for both conditions.

Verfaillie & d'Ydewalle however found clear differences between the two conditions. Firstly, in the initial condition, which was a direct replication of Freyd's original experiment, the predicted memory distortions were clearly discernable, yet when a direction change was implied in the second condition, the memory shift dropped almost back to zero. This tends to suggest that when viewers are presented with a coherent complex style of change, they anticipate the future course of events on the basis of the episode as a whole, rather than on the current motion path, as the analog to physical momentum would predict. These new developments also indicate that the class of changing patterns we are able to extrapolate, is much richer than a simple analogy to representational momentum dictates. Furthermore they provide evidence to demonstrate that the additional complexity of the inducing stage can lead to more diverse memory distortions than those found by Freyd and colleagues in their experiments involving simple monotonic translations or rotations.

It is of interest to note here, Freyd has previously stated that representational momentum will occur in any dimension affording continuous change, so long as this change could be extrapolated into the future (Finke & Freyd, & Shyi, 1986). She substantiated this claim by showing that permutations in the inducing display (i.e. incoherent sequences) no longer created distortions in memory. However, in Verfaillie & d'Ydewalle's study, the inducing sequence was not coherent in terms of following an a-b-c pattern, but it was predictable in that it was made up of eight inducing patterns in which the orientation of the rectangle changed periodically in a foreseeable manner. It now appears that it may not necessarily be the coherence of the sequences as such which created the memory distortions found in Freyd's experiments; but rather the predictable nature of the unfolding event. If this is the case, it could be suggested that Freyd's *incoherent sequences* could also be shown to exhibit "momentum-like" qualities if the pattern was repeated a few times within the inducing stage.

THEORETICAL IMPLICATIONS OF THE EMPIRICAL RESEARCH ON REPRESENTATIONAL MOMENTUM

Freyd has argued that representational momentum fits Pylyshyn's (1981) criteria of "cognitive impenetrability" in that subjects cannot instantly halt the represented movement no matter what they think or attempt.(Freyd 1992) However the assumption of cognitive penetrability seems dubious in light of the research findings of Kelly & Freyd, 1987. In their experiment studying auditory moment (Exp. 8), these researchers noted a marked difference between musically trained subjects and those without the musical experience. Their memory for tones rising and falling in pitch, was tested. While the latter group were shown to exhibit the predicted momentum effects, those with musical training were excluded from the analysis because not one of the subjects made an error. Kelly & Freyd argued that the intervals between the tones were simply not confusing enough for listeners trained to perceive pitches. A later study (Freyd, Kelly & DeKay) supports this assertion by showing that a forward memory asymmetry became apparent for musically trained subjects when the probe tones were close in frequency to the actual third tone.

It appears then, that in particular circumstances, a person is able to place a semantic interpretation on the task, and encode the stimuli differently. According to Phylshyn, this would provide indisputable evidence of cognitive penetration. He feels that if a form of an image can be altered in a particular way by changing what the subject believes the stimulus to be, or changing the subjects interpretation of the task, then the explanation must involve such constructs as beliefs, goals or tacit knowledge, rather than intrinsic properties of some medium.

The findings of Hubbard & Bharucha, 1988; Hubbard, 1990; and Verfaillie & d'Ydewalle, 1991 also seem to indicate, in contrast to Freyd, and in opposition to an analogy with physical momentum, that the extrapolation forward in time seems to pertain to the event as a whole, rather than being based on just a local pattern of movement. The size and the direction of the memory distortions recorded seem to be governed by what a person anticipates is likely to occur in the future. Therefore **predicability** emerges as a major factor in the memory displacement effect, yet it still appears that this anticipatory process is mandatory.

The point at which these apparent conceptual influences have their effect is not yet known, therefore it is not actually possible to dispute Fodor's (1983, 1985) modularity thesis of "informational encapsulation" of the perceptual modules as they perform their specialized tasks. To falsify modularity (i.e. to show a "top-down" influence) it must be demonstrated that the effect from the larger context and general knowledge is post-perceptual, and that the source of the information is from outside the module. If it is a post-perceptual influence, it would need to occur very rapidly because recall memory has been shown to be affected after extremely short retention periods (i.e. under 20 msec), and the memory changes appear to be quite resistant to both practice and error feedback (Finke & Freyd, 1985). Alternatively, rather than arguing for an "all-or-nothing" position, it may be wiser to adopt a previously stated position suggesting that the perceptual/representational system is hierarchically organised (Finke, 1980; Shepard, 1984). In this manner it could be argued that the lower processes may be automatic and impenetrable, whereas higher processes may be more open to influence by cognitive penetration.

FUNCTIONAL SIGNIFICANCE OF DYNAMIC REPRESENTATION AND MANDATORY ANTICIPATION

Shepard (1981) has argued that the perception of all objects depends upon a knowledge of their possible transformations. This ability is apparent by the ease with which we identify objects that are either partly obscured, or else shown at unfamiliar angles. We are able to do this because we are adept at correctly recognizing objects from many orientations. The premise that we may have stored knowledge about each object's possible orientations in long-term memory to enable a matching process to take place, seems to be an unlikely and implausible assumption (ct. Biederman).

Instead, it would seem more probable to suppose that we access a more abstract form of knowledge from our long-term store, and temporarily construct an image, operating on it as if it were part of a complete event.

This ability to present information dynamically has also been shown to provide a much enhanced perception of static forms, because it allows for the incorporation of pertinent information about the object's possible past or future status. This ability may aid recognition (e.g. of handwriting - Freyd, 1983a) or it may allow for a much richer appreciation of a static scene or display (e.g. viewing Art or photographs - Freyd, 1983b; 1992).

The ability to represent motion and forces is also said to have a degree of adaptive significance because it can help us anticipate the future course of events and plan our motor actions in our everyday lives. No matter what we do in our environment we must co-ordinate our movement with others, therefore it is imperative that we not only understand what would happen if our actions interfere with others (both stationary and mobile objects) but we must also have a perceptual system that is capable of representing situations.

The ability to extrapolate an object beyond a final observed position through mandatory anticipation, must also be helpful because it enables people to predict the future position of objects despite their inability to maintain constant eye contact. Reacting to a rapidly moving object (e.g. catching a ball or changing position in order to avoid a collision) are skills that require accurate anticipation of an object's future positions. Similarly, if a moving object becomes temporarily occluded (e.g. a bird flying behind a tree) then the ability to mentally extrapolate along the same motion path allows not only correct anticipation when it finally reappears, but also promotes the conceptual continuity of the event.

PRESENT STUDY:

Since many living things and moving objects can be seen and heard while moving in space, it is assumed that spatial representations would be abstract and not tied to any modality (Anderson, 1990). Furthermore, since both vision and audition deal with object movement, it is expected that auditory induced movement would tap into the same system, and hence lead to similar memory displacement effects.

It has been suggested that we group sounds according to their spatial origin (Bregman, 1990), therefore if sounds come from one place and begin at the same time, we tend to assume they most likely have the same source. If the auditory system is capable of grouping sounds by their location, it must have a method for representing locations on some sort of continuum. Space of course is physically a continuum, therefore the auditory system should behave as though there are a continuum of locations, and to get from one place to another, sounds should pass through all the intermediate stages.

Research by Rhodes (1987) has provided some evidence to suggest that auditory spatial information, like visual spatial information, is represented analogically. This means that the spatial relations and distance information are directly mirrored within the representational system. Therefore it is conjectured, if an object is heard to move in space, then by analogy to the representational momentum findings of Freyd & colleagues, the auditory system should automatically calculate the future position of the moving sound. It is therefore hypothesised that when a moving sound stops, a person's memory for the last heard position will be displaced forward in the direction of the movement.

Four studies are reported, with the aim being, to provide a demonstration of this claim.

CHAPTER 2

EXPERIMENT 1

INTRODUCTION

The main aim was to devise a procedure, based on Freyd's paradigm, capable of establishing similar memory distortions within the auditory domain. This decision was guided by the outcome of previous research (Kelly & Freyd, 1987, Freyd, Kelly & DeKay, 1990) which identified a forward memory asymmetry using implied changes in the pitch of a tone. That experiment identified a structural similarity between the memory distortions noted for pitch changes and those previously identified using visual stimuli. In order to further investigate memory for sound, it was planned instead to focus on the movement of a sound progressing in a linear fashion. This was thought to replicate the earlier visual experiments more closely because a change in location was again specified. This change was predicted to induce memory distortions consistent with the visual findings, since in our natural surroundings, the movement of a sound is commonly tied in to a moving object.

Since apparatus capable of driving only six speakers was initially available for use in this research, a method based on Freyd (1984), was followed. In that study, the standard inducing sequence consisted of three static displays, and the memory shift was determined by simply comparing differences in response time and accuracy for forward and backward distracter positions.

In order to avoid the perception of continuous motion, it was planned to relay a tone of the same pitch, to separate equally spaced speakers, at regular temporal intervals. If these speakers were shielded from the subject's view, it was hoped the display would be realistic enough to induce the belief that a sounding object was moving along behind the screen. In order to test for memory distortions associated with the implied sound movement, it was proposed to place identical speakers, an equal distance apart, on each side of the one delivering the to-be-remembered tone in each sequence. Subjects would then be required to make a "same/different" judgement based on their memory for the location of the final tone.

It was predicted that subjects would find a forwardly placed probe speaker more difficult to reject than a backwardly placed one (thus error rate and reaction times would be significantly higher in the former case) because a forwardly displaced speaker would represent a position that is closest to the "remembered" location. In order to demonstrate that the memory distortion relies on the consistency of the inducing sequence, it was predicted that when the presentation order of the inducing tones was permuted, the distortions would no longer be apparent. These hypothesised results are depicted graphically in Figure 4.

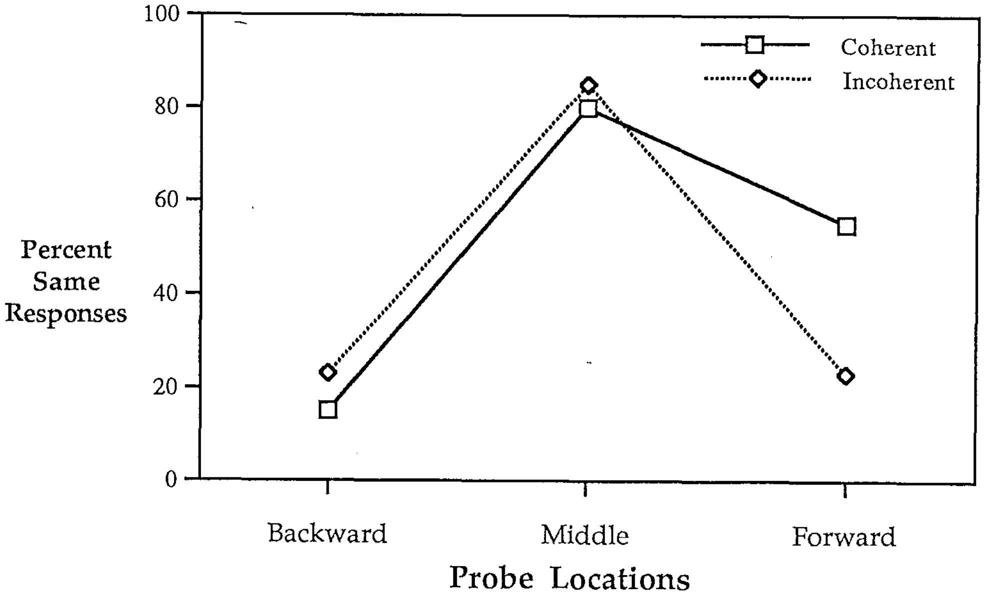

Figure 4: Hypothetical results of Experiment 1 displaying error rate as a function of probe position and sequence coherence.

METHOD

Subjects

Five female and five male unpaid volunteers participated in this experiment. All were under-graduate students from the University of Canterbury. Four had a background in Psychology, but all were naive to the experimental hypothesis. They were aged between 19-34 years (mean age 23yrs), and none had participated in pilot studies associated with the experiment.

Apparatus

The required apparatus was set up in a dimly lit room (6.7m x 4.7m) which was well isolated from outside sounds. A Superlux desk lamp with a 40 watt bulb, was placed on the desktop about 2 metres away from the subject, and provided the only illumination.

Four corresponding speakers 10cm in diameter, were suspended by wire from the ceiling to eliminate differential resonance effects from supporting surfaces. These were placed at the approximate head height of a seated subject, with each speaker arranged in linear fashion, with a centre to centre separation of 1 metre. The third speaker (in a Right to Left sequence) was placed 1.2 metres directly in front of the subject.

Two additional matching speakers were positioned at head height, at centre to centre distances 15 cms each side of the third speaker. These latter speakers provided the probe sounds in the experiment. (refer Fig.2). Pilot studies had suggested wide differences in the ability of subjects to remember the location of the final tone in a sequence. The particular probe locations were chosen because, at this spatial separation, the task appeared neither impossibly difficult nor trivially easy.

A thin black curtain was draped from ceiling to floor, concealing the entire display from the subject's view, and providing a constant background, devoid of identifying features which could convey locational cues to the subject.

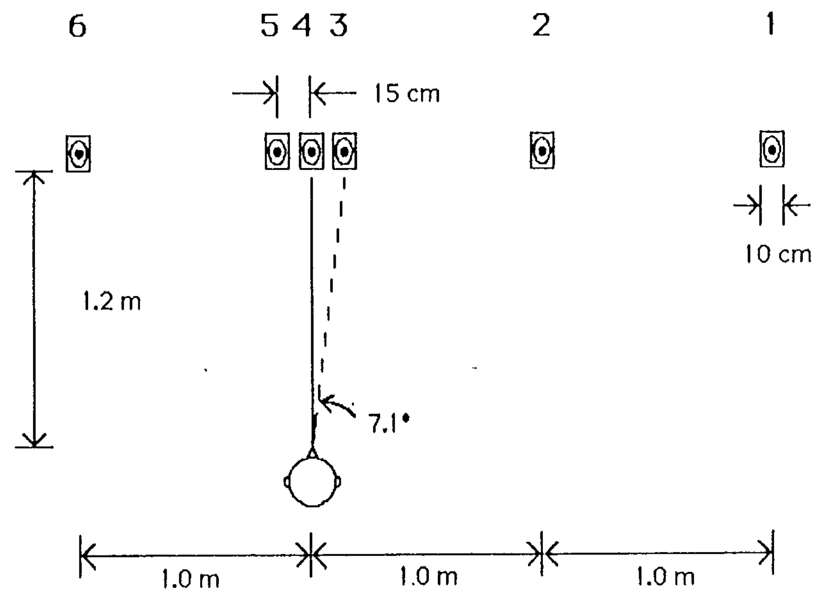

Figure 5: Plan view of experimental layout.

A set of three morse keys, mounted in a semi-circular fashion on a wooden board, was positioned on the bench in front of the subject's seat. This provided the response medium for the experiment. Pilot studies revealed that subjects found Freyd's (1984) two key "same-different" procedure awkward, because probes, perceived to be on one side of the final inducing tone, often called for a response by the contralateral hand. The current array proved to be in spatial accord with the subjects perception, irrespective of sound direction or probe location, thus affording a more compatible system of response mapping.

The entire experiment was controlled by an APPLE II + Computer which was placed out of view of the subject. This generated the tones via an assembly language routine which toggled one of the four games paddle annunciator outputs, the cassette output, or the onboard speaker, at the desired rate and for the required duration. The output from each of these was directed to a separate National LM383 semiconductor amplifier, which in turn fed through a variable resistor to a speaker. Tone wave form and frequency was verified by oscilloscope and a Trio DF-760 frequency counter. The computer also recorded the outcome of each key press response in relation to sequence direction, and measured response latencies to 1 msec accuracy via a further assembly language routine. A small foot pedal, placed beside the subject's seat, permitted subject initiation of each block of trials.

STIMULI

The inducing sequences consisted of 880 Hz square wave tones, with probe tones for each trial being selected at random from a frequency range between 400 and 700 Hz. The probe tones differed in frequency from the inducing tones, so that their difference from the inducing sequence became obvious. Also, pilot studies had revealed that when probe and inducing tones were of the same frequency, some subjects were able to use subtle timbre differences between the outer probes and the final inducing tone, as a basis for their location responses. The task of course called for responses based solely on locational difference. Making the tones from all three probe locations different by altering their frequency, forced all subjects to respond to locational differences.

All speaker locations (including probe speakers) were set at a loudness level of 50 dBA (at 800 Hz) using a Bruël &

Kjaer (Type 2235) Precision Sound Level Meter. This measurement was taken at subject head position so that the tones in the inducing sequence were equal in loudness and therefore did not increase on approach. This eliminated the possibility of any memory distortions arising simply from changing levels of loudness.

The onset duration of each tone (inducing and probe) was set at 200 msec. For the tones in the inducing sequence, this was followed by an off-set period of 100 msec. Probe tones followed the final inducing tone after a 500 msec offset interval.

The inducing tones all began to the subject's right, with the final tone in the sequence stopping immediately in front of the subject. The limited availability of equipment precluded the possibility of systematically varying sequence endpoints, or of investigating directional influences using the same group of subjects. While Freyd (1984) successfully demonstrated her memory displacement effects using a single endpoint, pilot work with the present study identified this as a problem. It became evident that subjects did not always concentrate on the entire sequence as requested, but instead attended to only the final location. To overcome this problem, distracter sequences with varying starting and finishing positions, were introduced. These were included only to create some unpredictability and they were not used in the data analysis.

EXPERIMENTAL DESIGN

Six blocks of trials were presented in total, the first three of which were treated as practice. The first block (Demonstration Block) consisted of only six trials which were designed expressly as a brief introduction to the equipment and the general procedure. The sequences in this block used all the four inducing speakers as starting positions, and the presentation order remained the same for each subject. However, the trials in this block were composed of quite different sequences to those contained in the main experimental blocks (refer Appendix B, Table 1), and the temporal interval between the tones was doubled. This effectively halved the presentation rate so that subjects had extra time to comprehend task requirements. Each subject was required to make two "Left", two "Same" and two "Right" judgements at this stage, thus bringing into play all three response keys if each probe was correctly identified. Subjects were given accuracy feedback by the experimenter after each trial.

Two further training blocks followed. Each of these consisted of 36 trials comprising each of the *Experimental* and *Distracter* sequences, presented in *coherent* and *incoherent* forms. These trials were identical to those used in the subsequent experimental blocks but the task at this stage differed slightly. Subjects were currently instructed to make only a two-way discrimination which required the use of only <u>two</u> of the morse keys. Before commencing each block, they were informed whether it would involve a *"same versus right"* judgement (Right Practice) or conversely, a discrimination between *"same and left"* (Left Practice). Each of these practice blocks contained twice as many "backward" (or "forward") as "same" trials, so that over the two blocks the three responses were equally probable. (See Appendix B, Tables 2 & 3). The starting order of each of these two practice blocks was counterbalanced across subjects.

The main aim of these blocks was to ensure subjects became proficient at making the judgements and registering the decision, as quickly and as accurately as possible. It must however be stressed, that feedback, relating either to accuracy or to the ability to follow task requirements, was NOT provided at this time, nor at any future stage of data collection. Instead, a few words of general encouragement which were independent of the pattern of responding, were relayed to each subject at the conclusion of every block of trials.

The experimental hypothesis was in relation to the inducing sequences and responses presented in the subsequent three blocks of trials. Each of these blocks was made up of 48 trials, consisting of 12 conditions, which represented an equal balance across Probe Position (i.e. Backward, Same, Forward); Sequence Type (Coherent, Incoherent); Required Key-Press Response (Right, Middle, Left); and Direction of Movement (Left, Right) - see Appendix B, Table 4. The sequences of greatest interest were those relating to speaker positions 1...2...4 (Experimental Coherent Sequences) which were probed with speakers 3, 4 and 5. These sequences all began to the right of the subject, and finished directly in front of them. (Refer to Fig.1). However, as there was a need to create some degree of uncertainty (as mentioned previously), Distracter Sequences, following the same balanced format as previously outlined, but using different speaker and probe positions (6...4...2 with probes at 3, 2 & 1) were also included.

Incoherent sequences, involving a permutation of each of the two previous presentations, were also included. These were intended to induce no forward memory distortions since a consistent patterns of movement was no longer implied. Each block of 48 trials in the experimental stage, consisted of six repetitions of the experimental sequences (i.e. coherent & incoherent forms) plus two repetitions of the distracter sequences (coherent & incoherent). A different random order of trials within each block was determined by the computer for each subject.

There were also three types of responses each subject could make. These were based solely on a judgement of the location of the fourth tone. In 1/3 of the trials, this tone sounded from the same speaker as the final inducing tone. For the remaining trials, this fourth tone was displaced either somewhere to the right or to the left of the last tone in the sequence. These displacements were represented with equal probability.

The task now required a high level of concentration since the starting and finishing points varied between trials, the tonal direction changed unpredictably, and the subject was required to make a difficult discrimination.

PROCEDURE

Subjects were tested individually in a session lasting approximately 45 minutes. The nature of the task and the procedural requirements were explained orally by the experimenter, who followed a standardized format set out on a written instruction sheet (refer Appendix A - Handout 2) A signed consent to participate was also obtained from each subject (see Appendix A - Handout 1, for an example of this form).

The task was such that each subject was required to listen to a sequence of three brief inducing tones, and to remember the location of the third sound in the sequence. They indicated the remembered position of this final tone, by reporting whether an ensuing probe tone of a differing pitch, had sounded from the same location, or whether it was displaced to the left or to the right. To do so, they were instructed to place the index finger of their preferred hand gently on the centre key in front of them. Subjects were informed that they were to press the centre key if the final tone in the sequence and the probe tone sounded from exactly the same location. If they thought the probe was to the left of the final tone they were to use the key to the left, and similarly, the right key for probes perceived to be to the right. They were told to expect 1/3 of the probe trials to come from the same place as the last tone in the inducing sequence, with the remaining trials being equally displaced somewhere to the left or right. This distribution therefore called for an equivalent number of responses at each morse key, should a subject correctly identify all the probes. At all times **accuracy** of responding was stressed over speed.

Each block of trials began with a verbal request for the subject to place goggles over their eyes, assume the required position on the rear of their seat, and prepare to focus their gaze directly in front of them. The need for eye goggles was recognised when pilot data indicated tht subjects will visually search for any available "landmark" to aid localization.

A firm reminder to refrain from making any head or eye movements during each sequence was also relayed to each subject. If this factor was not controlled, subjects may physically "track" the sound, and be unable to stop the eyes or head from moving after the sequence had ended. A head position which remained relatively constant throughout each trial was also deemed to be a necessary factor (approximately 0° azimuth and 0° elevation), to allow subjects to make accurate and comparable judgements across the two critical probe locations. Finally, subjects were informed of the importance of concentrating on the progression of the entire sequence of sounds during each trial. This instruction was given to minimize the possibility of subjects mentally "fixating" on a particular spatial position, and subsequently using this as an anchor for a locational judgement based on only the final tone in the sequence.

Subjects were next requested to position the index finger of their preferred hand gently on top of the centre response key, and to press the foot pedal to initiate each of the designated blocks of trials, whenever they were ready to begin. Once the foot pedal was pressed, a 1 second delay followed before the first tonal sequence began. Ensuing trials began automatically 1 second after subject's key press responses. This pattern repeated without further commentary until the designated number of trials in each block was completed. Should a subject press a response key before either a sequence had finished or the probe tone had sounded, the trial was deleted and re-introduced later within the same block.

At the completion of each block of trials, subjects were invited to remove the goggles and relax for a few minutes. During this time, response data were displayed on the computer screen, for the experimenter to view out of sight of the subject. After a suitable rest period the next trial block was presented.

When the experimental session concluded, each subject was thoroughly de-briefed in regard to the hypothesis and the expected results. An opportunity was also provided for subjects to discuss their pattern of responding with the researcher, if they should wish to do so.

RESULTS

All subjects reported the subjective experience of hearing <u>one</u> sound or sounding object moving along in front of them behind the screen. While eye and head movements could not be monitored, all subjects reported that they felt no tendency to move their heads or eyes since the duration of each tonal sequence was so brief.

It will be recalled that subjects were presented with the possibility of making two types of error at each probe point. A tone from a backward probe could be mistakenly identified as being in the same place or maybe forward of the location they had been requested to remember. Similarly, a forwardly displaced probe tone could be mis-interpreted as having sounded from the same place as the third tone or perhaps backward of it. Finally a probe tone sounding from the identical speaker to that of the to-be remembered tone, may be judged either forward or backward of that position. The raw data pertaining to these responses for each of the ten subjects, is presented in Appendix C, Table 1 while the table below displays these data in a summarized form.

Table 1: Percentage distribution of total responses recorded by subjects (N=10) at each probe point within the experimental sequences.

	BACKWARD PROBE			SAME PROBE			FORWARD PROBE		
	Bwd	Same	Fwd	Bwd	Same	Fwd	Bwd	Same	Fwd
Coherent Sequences	*70.6*	23.9	5.5	25.6	*60.5*	13.9	10	46.1	*43.9*
Incoherent Sequences	*63.9*	31.1	5.0	23.3	*61.1*	15.6	7.8	49.4	*42.8*

Table 1 identifies the response choices favoured by subjects by presenting their total key-press responses as a percentage of the number of trials (n=180) at each probe point. The figures in italics identify the percentage of correct responses within each category. As predicted, subjects were noticeably less accurate in correctly identifying the forwardly displaced probe tone compared to the equally displaced backward probe. Subject's judgements also displayed a decreasing level of accuracy in the direction of the implied movement, according to the hypothesis.

When percentage errors are viewed in terms of a comparison between *"same"* responses at each probe point, the strategy employed by Freyd & Finke (1984), the contrast between the outer two probe points becomes more distinct (see Fig.6). It is observed that the forwardly displaced probe tone within the coherent sequences, was identified as being at the same location as the final tone in the sequence on 46.1% of the trials. This compares with the 23.95% of backward trials for which the same error occurred. A paired *t*-test on each subjects "same" responses across these two categories, identified this difference as being statistically significant ($t\ (9) = -2.065$, $p < 0.05$, 1-tailed).

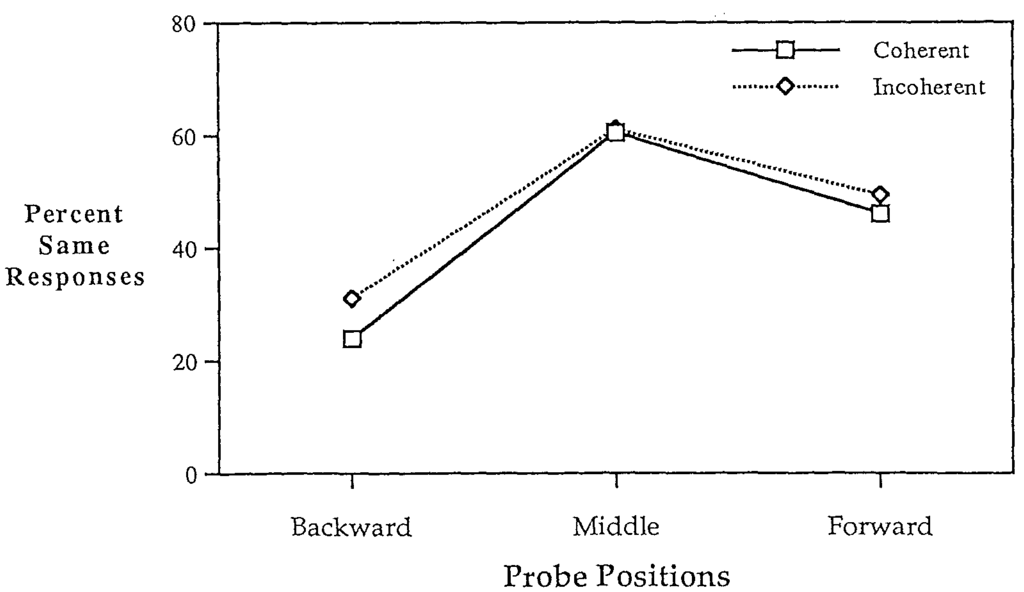

Figure 6: Percentage of "Same" responses as a function of probe position and sequence type.

While error rates were much higher than those found in similar visual experiments, the overall level of accuracy was still shown to be very satisfactory. Since subjects were given the opportunity to respond in one of three ways to each probe tone (i.e. backward, same or forward), they had a 1 in 3 chance of guessing the correct response. To assess this possibility, the mean number of correct responses per subject was found for each probe point. This was compared to a level indicative of chance responding (i.e. 6 correct identifications at each probe) using one sample *t*-tests. These revealed that the overall accuracy was significantly greater than chance for both the backward probe (t (9) =4.56, p <0.001, 1-tailed) and the centre probe (t (9) =4.77, p <0.001, 1-tailed). Subject responses at the forward speaker location however did not differ significantly from chance.

While the predicted effects were noted for error data within the coherent sequences, no significant patterns emerged when subject response times were compared. The mean reaction time (RT) for correctly identifying the probe speaker placed slightly forward of the "true position" should have been markedly slower than the speaker placed an equal distance backward. Yet, the opposite trend was noted, with the mean time for a correct identification of the backward condition being 941.17 msecs, which was slightly slower than the average 922.76 msec it took subjects to accurately record a response in the forward condition. This was not seen to be a problem for the hypothesis because it is now accepted that measures based on reaction times can be unreliable (Finke et al, 1985) since subjects can make an insufficient number of responses within a condition to calculate a reliable reaction time. This was particularly evident in the present study, with some individuals making a correct response on as few as 6% of trials.

However, the most obvious feature of the results is the observation that in opposition to the original prediction, the incoherent sequences also produced a pattern of responses consistent with a motion induced memory displacement. Table 1 clearly shows just how similar the level of responding was across these two sequence types, with error rates (i.e. percentage of "same" responses) between backward and forward probes still being very different. However, application of a *t*-test to subject frequency of "same" responses just failed to reach significance, (t (9) $=-1.74$, $p <0.058$, 1-tailed).

In accord with results for the coherent sequences, one-sample *t*-tests revealed the mean number of correct responses to exceed chance for backward probes t (9) =4.53, p <0.001, and centre probes t (9) = 3.98, p <,01, but not for forward probes t (9) = 1.116, p = 1.46 n.s.

DISCUSSION

As the localisation judgements in this experiment are believed to be based primarily on interaural temporal differences which are assumed to dominate at lower frequencies (Yost & Neilson, 1985), and the probe speakers were placed at an equal angular distance from the central point of the subject's head, there should be no difference in the level of accuracy between these speakers. The results however clearly show that, on average, subjects found it considerably more difficult to reject a forwardly placed "probe" compared to a correspondingly positioned backward one. Since this difficulty arose with the speaker placed forward of the to-be remembered location, and in the direction of the movement, it would seem that this response asymmetry could only be interpreted as providing further evidence for a motion induced forward memory displacement effect.

Perhaps most significantly though, the present findings have failed to show a difference between the coherent and incoherent sequences, with memory distortions consistent with momentum predictions, being obtained for both sequence types. This seems to seriously question the validity of a conclusion for a motion induced memory effect, since Freyd & Finke (1984) used the lack of coherence as a control condition in their original study. While this finding would appear to immediately negate the hypothesis, it could be argued that a tone being relayed in a speaker order of 2...1...4 (refer Fig.5) could still create a forward memory displacement based on the interpretation of a rapid Right-Left movement between the second pair in the sequence. In fact, this explanation is compatible with the research findings of Freyd & Johnson, 1987. In a control condition, using an incoherent sequence of rectangular orientations, it was shown that by varying the inter-stimulus intervals between the first and second, and second and third rectangle positions, while holding stimulus durations constant, a positive memory shift can still be obtained (Exp. 4). These researchers contend that this momentum effect was obtained from only the last two stimuli presented.

Similarly, while the incoherent sequences in the present study may appear to be neither systematic nor predictable, it will be recalled that they, like the coherent sequences, all commenced to the right of the subject, with the final tone stopping immediately in front. It is therefore quite feasible to contend that subjects learned to anticipate the sound trajectory on the basis of the starting position of the sequence. It is perhaps significant that no remarks were made about the confusing nature of sequences from the right, whereas the distracter sequences, which began either to the left of subject or directly in front of them, prompted many comments.

Although the experiment produced the expected patterns of results in terms of a difference in memory between the two outer probe speakers, there is the possibility that this could be explained in terms of factors that are independent of the temporal order of the tones, or the spatial positioning of the speakers. A major concern would be a slight, but detectable difference in the timbre of one of the probe speakers. This could be caused by a slight dissimilarity between the speakers or some variation in the acoustical properties of the room. This could create the situation whereby sounds from one speaker may be more distinctive than sounds from the other, (even though probe pitch varied from trial to trial), with the consequence that one speaker may have been much easier to distinguish. It is very important to rule out such an explanation for the effect, therefore the following experiment is aimed at specifically addressing this concern.

EXPERIMENT 2

INTRODUCTION

If the noted differences in error rates in Experiment 1 were solely attributable to an inherent characteristic of one of the probe speakers, this factor should become apparent if the function of each probe speaker is reversed by changing the direction of the main experimental sequence. While it is acknowledged that the influence of speaker acuity and sound direction would have been addressed most adequately by incorporating these variables into the original design, such an option was not possible due to limited availability of equipment. Instead it was proposed to address these concerns by altering the locations of the main speakers to accommodate a change in direction, and repeating the experimental procedure with a new group of subjects. The prediction of course being, that the pattern of results obtained will again reflect the direction of the motion. If so, the probe location producing low errors in Experiment 1 should be associated with a high incidence of errors in this current experiment.

METHOD

SUBJECTS

Ten subjects also participated in this experiment. All were female under-graduate students from the University of Canterbury. They ranged in age from 20 - 31 years (mean age = 22 years). Each subject was naive to the hypothesis in question.

APPARATUS

The apparatus was identical to that used for Experiment 1 except that the three main speakers used in the inducing stage were rearranged to accommodate the sound sequence coming from the opposite direction. To achieve this, Speaker No.1 (refer Fig.5) was moved to a position two metres to the left of the seated subject, and Speakers 2 & 6 were exchanged. The "probe" Speakers, plus Speaker 4, which delivered the final tone in the sequence in the first experiment, remained in exactly the same places as before, In effect then, all the locations were represented by the same speakers as in the previous experiment, except that now, the outer probes served the opposite function. It is important to note that loudness levels of the speakers remained equal at subject head position, and that neither the positions nor loudness levels of the three probe speakers were altered from Experiment 1.

STIMULI AND PROCEDURE

The stimuli used in this experiment, and the procedure followed, corresponded to those of Experiment 1, except that the main experimental sequences now moved from the left of the subject to their right, and the distracter sequences also represented a change in direction. This had the effect of reversing the order of the conditions relating to the two probe speakers (i.e. Backward and Forward) as well as reversing the key press responses required to correctly identify these probe positions.

RESULTS

Again the raw data pertaining to the responses made by each subject are presented in Appendix C Table 2, while the percentage distribution of responses registered by all the subjects at each probe location, are displayed in Table 2 below. An unexpected finding is that the anticipated difference in the probe speakers occurred in the opposite direction to that hypothesised. Unlike the previous experiment, subjects now showed a tendency towards identifying the backward probe tone as representing the location of the tone they had been requested to remember. A paired *t*-test, assessing the number of "same" responses registered by subjects at these two probe points within each coherent sequence, identified no significant differences.

Table 2: Percentage distribution of the total responses made by subjects (N=10), at each of the three probe locations.

	BACKWARD PROBE			SAME PROBE			FORWARD PROBE		
	Bwd	Same	Fwd	Bwd	Same	Fwd	Bwd	Same	Fwd
Coherent Sequences	***35***	49.4	15.6	11.7	***56.1***	32.3	10	37.2	***58.8***
Incoherent Sequences	***28.3***	52.8	18.9	10.6	***59.4***	30	4	35.6	***60***

This tends to suggest that subjects found it equally difficult to make a correct identification of either outer probe speaker. However further statistical analyses revealed that the level of accuracy at the forward probe, unlike that of the backwardly placed speaker, was significantly better than would be expected to occur by chance alone (t (9) = 3.96, $p < 0.01$, 1-tailed). Similarly, subjects judgements registered in relation to the central probe site were also regarded as being reasonably accurate (t (9) = 3.01, $p < 0.01$, 1-tailed).

Like the first experiment, a change in the order of the tonal presentation within a sequence, proved to be of no noticeable consequence. Both coherent and incoherent sequences produced a pattern of results which statistical analyses indicated were very similar.

DISCUSSION

The results from the current study do not provide evidence in support of the hypothesis, and, by failing to do so, they represent a complete contrast to the assumptions posited in Experiment 1. It would now seem that the response asymmetry of the earlier study, which was then attributed to a mandatory anticipation effect, may in essence, have been created by the non-equivalence of the two probe speakers. This would appear to be the inevitable conclusion based on the findings which suggest that when the functions of the probe speakers are reversed (without a change in position), there is no corresponding change in the proportion of errors made at these locations.

It may still be possible though that an another factor has contributed to the incompatibility of the results. An interesting observation is the imbalance in the number of key press responses within the experimental phase. This appears to be independent of key function or sound direction. It will be recalled, that in both experiments there was an equal probability of the probe tone presenting at each of the three locations, thereby creating the situation where each response key would be pressed equally often if subjects were completely accurate. The total key press responses registered by subjects throughout the experimental sequences of both studies are presented graphically in Figure 7. These indicate a clear difference in responses registered at each morse key, with subjects displaying a marked preference for the central response key. It was of course the case that each subject had their index finger poised to respond at the central key, which may well account for this finding.

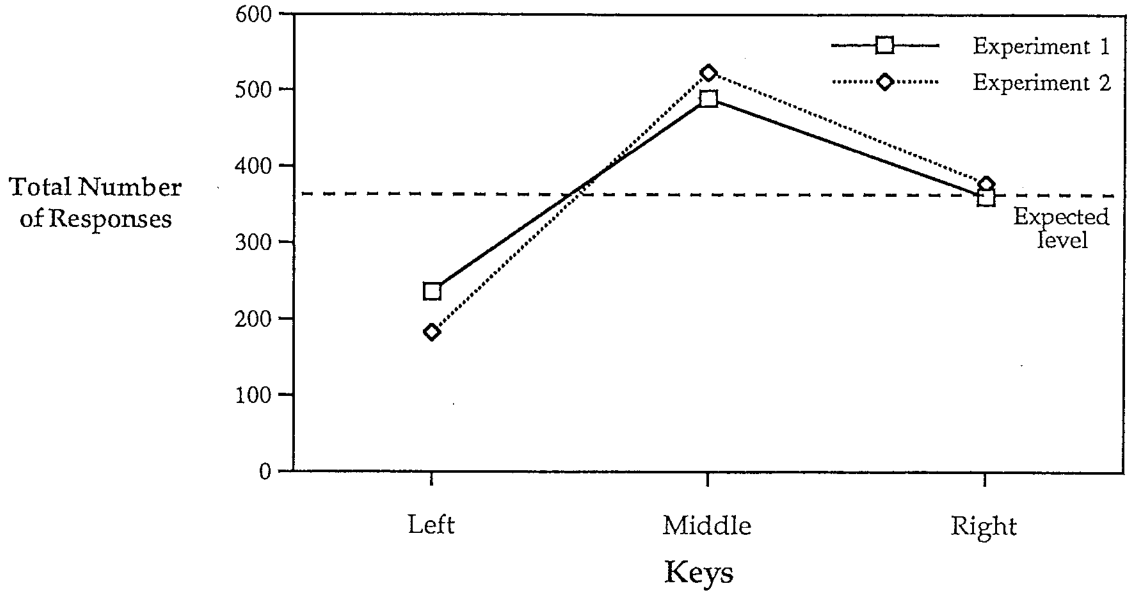

Figure 7: Total number of responses registered as a function of key position and experimental procedure.

The two outer morse keys differed in the total number of responses they attracted (t (19) = 6.09, $p < 0.002$, 2-tailed), with the left key attracting the least attention. This left key corresponded to Probe Speaker 5, which acted both as a "forward probe" in the first experiment, and a "backward probe" in the subsequent study. This probe position produced very high error rates in both experiments. Of course it is not possible to determine whether a response bias has contributed to the unexpected findings or whether one of the outer probe speakers had a uniquely characteristic sound.

Constraints caused by the availability of only six speakers in the present study, resulted in procedures likely to be insensitive detectors of movement induced memory displacement. The inducing sequences were short, the spatial separation between speakers was perhaps excessive, and a common endpoint directly in front of the subject, occurred on all trials. It is evident that an alternative procedure, less biased against the demonstration of the memory displacement effect, is needed. Further studies, incorporating a procedural change, are reported in the next chapter.

CHAPTER 3

EXPERIMENT 3

INTRODUCTION

In the present context, the more direct method used by Hubbard & Bharucha (1988) had appeal. These researchers successfully used an apparent motion paradigm to demonstrate a similar memory displacement effect to that identified by Freyd and colleagues. Their subjects followed a small dot which was observed to move in a linear fashion across a computer screen. This dot was then shown to disappear at one of five pre-arranged positions. The subject's task was simply to position a hair-line cross over the vanishing point of the dot. They were shown to misplace the cross in the direction of movement with the degree of this displacement increasing with dot velocity.

In the current study, subjects tracked a sounding object which was hidden from view, and they indicated the "vanishing point" of the sound by directing the beam of a laser pointer to the location. The prediction is, that the judged vanishing point of the tone will be displaced forward of the true vanishing point, in the direction of the motion.

METHOD

SUBJECTS

Fifteen unpaid volunteers participated in this experiment. All were first year Psychology students from the University of Canterbury. The 4 male and 11 females were aged between 18 - 32 years, with a mean age of 21 years. All indicated they were right-handed.

APPARATUS AND STIMULI

Thirty one, 10 cm diameter AXENT speakers (model 10G45P) were adjacently mounted on the lower edge of a 3.5 metre 13x2cm wooden plank which was suspended from the ceiling. The entire display, which extended almost the length of the 3.7 x 3.5 metre room, was positioned at the approximate head height of a seated subject. Black cotton curtaining was draped from ceiling to floor to conceal the speakers from view, and to provide a uniform background as devoid of landmarks and visual anchors as possible.

A 2.5cm square black aluminium rod spanning the entire display, was mounted in timber supports each side of the room, and positioned directly in front of the curtain. A measuring scale consisting of 1 centimètre demarcations, with identifying numerals every 5cms, was drawn on one side of the bar. This enabled accurate identification of the location of the pointer beam, and hence the remembered vanishing point of the sounding object. Subjects indicated the vanishing point by pointing the beam of a PLUS laser pointer (Model LP-010) at a blank side of the black rod. The experimenter then activated an electric motor which rotated the rod, bringing the measuring scale into view. After entering the numerically coded location into the controlling Apple II + computer, the rod was again rotated to expose a blank side in preparation for the next trial.

Purpose built circuitry was constructed for the experiment. This allowed a sequence of brief sounds to be generated, beginning either at the extreme left or extreme right speaker. These sounds could be relayed inwards from speaker to speaker in either direction, for a predetermined number of speakers. The duration of each sound, and the silent interval between the sounds from successive speakers, was determined to within millisecond accuracy by an Apple II + computer, using its onboard oscillator and assembly language software. The tones were produced by a tone generator, external to the computer. An oscilloscope display revealed the sounds to be a basic 400 Hz square wave tone with a superimposed onset click. The resultant sound was somewhat similar to the bells heard at a railway level-crossing.

The loudness level of each speaker was adjusted to 57dB, using a Bruel & Kjaer (Type 2235) Precision Sound Level Meter. Measures were taken with the instrument placed at subject head height, 1 metre directly in front of each speaker. Unlike the previous experiment, the aim was to equate the energy output of each speaker, not to equate their loudness at the location of the subject. The sounds now showed a slight, yet discernable, increase in loudness as they progressed towards the subject. It was not possible, within cost constraints, to obtain variable resistors with sufficient range, to permit the equation of loudness levels of the 31 speakers at the position of the subject.

The sound sequences were programmed to begin from either end of the linear arrangement, with each speaker regulated to sound a tone for 100 msec. This was followed by an off-period of 10 msec, after which time the next adjacent speaker sounded. This represented a sound travelling at the approximate rate of 1 metre per second. Pilot studies suggested this particular stimulus onset asynchrony provided a realistic impression of a sounding object progressing in a consistent manner behind the screen. Selecting the optimal speed for the sound required careful consideration. If the sounds progressed too slowly it became possible to count the number of sounds in the sequence and this could be used as a basis for the localization judgement each time, whereas on the other hand, if the sounds moved too quickly they could not be tracked.

The experiment was conducted in a dimly lit room, with the only illumination being provided by the 22 watt fluorescent MAGGYLAMP positioned next to the experimenter. Stimuli were presented in 33 trial blocks, with all the stimuli in a block representing motion in one direction. The motion stopped at one of 11 termination points, with each location point being probed 3 times in the 33 trial block. Within each block, the stopping positions were determined randomly, with a different random order being used for each block and each subject.

For the purpose of identification, each speaker was imagined to be numbered inwards from speaker 1 at each end (left or right). For each direction, stopping locations of 14 - 24 inclusive, were used. The subject sat directly in front of speaker 19 (which was midway between the stopping locations) on a 66cm high chair, placed 2 metres in front of the line of speakers. It will be noted that subjects were not seated in the middle of the 31 speaker array. Instead, their position was determined by the direction of the motion, with a change in direction involving a re-positioning of the chair to allow a minimum sequence of 14 speakers to sound on any one trial. It was hoped that the longer sound sequences would serve to enhance the implications of motion, thus increasing the likelihood of detecting a movement induced memory distortion.

A foot pedal, positioned at the base of the subject's chair, enabled subjects to initiate their own trials.

PROCEDURE

The experiment consisted of four blocks of 33 trials, each preceded by a short practice block consisting of 11 trials. These practice blocks probed each of the end positions due to appear in the forthcoming block, and the same random ordering of these practice trials was presented to each subject. The experimental blocks were paired according to sound direction, with half the subjects completing two blocks with left to right movement before right to left. Each block was separated by a short recess.

The experimental session began with each subject having the task explained to them by way of a standardized instruction sheet (refer Appendix A - Handout 3). They were asked to follow the wording while the information was being conveyed orally by the experimenter. Subjects were informed that on each trial they would be aware of a sound moving either from left to right or right to left, behind the black curtaining in front of them. The starting position of the tone would be predetermined before each block began, and the direction would remain constant throughout a complete block of 33 trials. They were instructed to concentrate very carefully on the progression of this sound and try and locate the *exact* position at which the last sound occurred. The need for accuracy was stressed.

Each trial was initiated by the subject depressing the foot pedal placed next to them. After a 1 second delay, the first sound sequence commenced. Prior to this, the subject had been requested to focus their eyes on a small white cross painted on the black bar directly in front of them. The instruction being, that they were not to move their head or eyes during each trial until the sound ceased. This was in direct response to findings in the pilot studies, which indicated that the uncontrolled movement of the head or eyes appeared to inhibit the accuracy of the localization judgements. In these situations, the sound sequence appeared to be progressing at a rate faster than eye or head movements could monitor. Consequently, this created an identifiable "memory lag" effect, since many subjects were noted to conclude that the sound had terminated at a point noticeably backward of the true position. Such an effect was not in evidence when a fixation point was incorporated into the procedure.

Once the sound stopped, subjects were instructed to respond immediately, and identify the location at which they last heard the sound. This was achieved simply by pressing a button on the laser pointer held in their right hand, and directing a small beam of light onto the black bar positioned in front of the curtain. The experimenter then activated an electric motor which rotated the aluminium bar to reveal the measuring instrument on the reverse side. The identified position was recorded onto a numeric key pad, from where it was registered by the computer. As an accuracy check, the entry was displayed on the computer screen for the experimenter to view, and the subsequent trial could not begin until this information was deemed correct by pressing the "Enter" key.

Subjects were also informed of the importance of re-focusing not only their eyes, but also their complete attention back to the centre point after the completion of each trial. This was to prevent their response judgements being influenced by the finishing point of the previous trial. The instruction was also given, that should a subject discover their performance on any one trial to be impaired due to distractions or inattention, they must inform the experimenter of this fact immediately. It was explained to them that failure to do so, would seriously affect the overall accuracy of their results. Since the facility to re-schedule a trial was not provided in the software, any such trials were simply deleted.

After each experimental block there was a short recess to provide subjects with a few minutes break from the task, and to enable the experimenter to re-position the chair to accommodate a change in sound direction when the need arose. Each block of trials took approximately 10 minutes for subjects to complete, and the entire session was comfortably completed in just under one hour. At the conclusion of each session, subjects were thoroughly de-briefed with regard to the hypothesis and expected results. Arrangements were also made for each subject to collect a full written summary of their results plus the overall pattern of findings, at a pre-determined future time. It is important to note, that up until the completion of all the experimental blocks, no feedback was given to any subject with regard to their performance.

RESULTS AND DISCUSSION

While each subject was provided with the opportunity to reject trials on which they felt their ability to locate the sound accurately had been compromised, only three chose to do so. In these cases a maximum of two trials were eliminated, and these were distributed across probe points. The data from one male subject were excluded from the analysis after initial concerns about his ability to attend to the task, were substantiated when mean average deviations at each of the probe points were noted to be unacceptably high. Subjects also reported no tendency to move their eyes from the fixation point. Head movements were monitored at random by the experimenter. No such movements were observed. (Refer Appendix C, Table 7 for analysis of Variance Summary Table. Note the conservative degrees of freedom used.)

For each sound sequence, the perceived vanishing point was expressed as a deviation from the actual vanishing point; with positive deviations indicating the vanishing point to be perceived to the right of its true position. Conversely, negative deviations signalled a displacement to the left (refer Appendix C, Tables 3 & 4 for subjects raw data).

Figure 8, presents the mean displacements (reported in cms) as a function of both the direction of apparent motion, and the location of the speakers relative to seated subject.

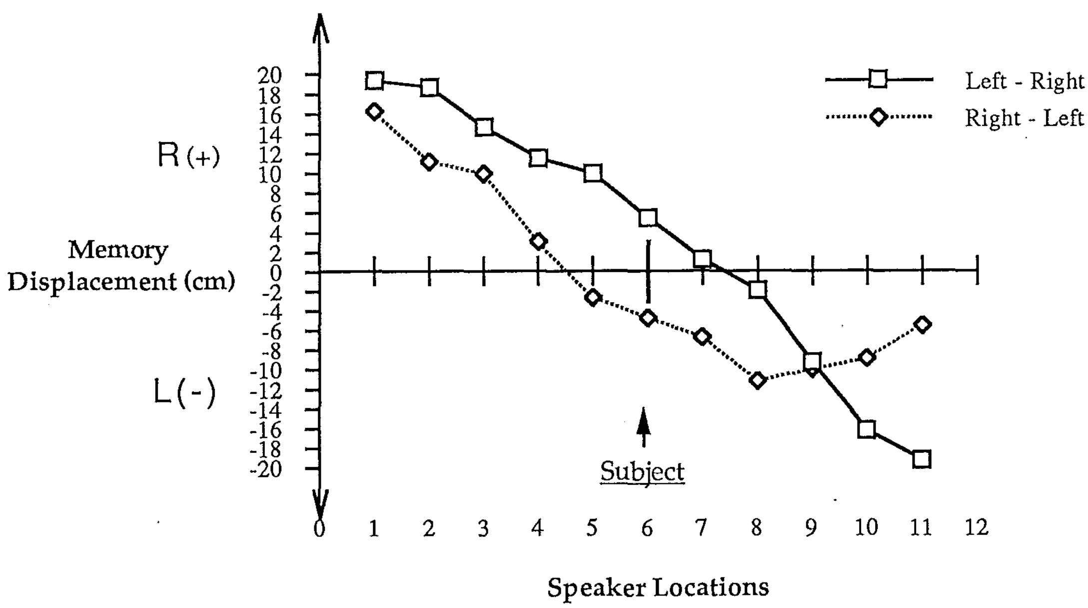

Figure 8: Experiment 3, mean deviations at each speaker position as a function of sound direction.

It will be recalled, subjects were repositioned depending upon direction of motion, to allow longer inducing sequences. Consequently, each speaker location indicated on the horizontal axis in Figure 8, actually refers to two separate speakers at different absolute locations. These speakers are thought to be at corresponding positions, relative to the subject.

On the graph, the points above zero indicate mean displacements to the right of their true location, while points below this line, specify displacements to the left. It will be noted that, regardless of direction of movement, vanishing points on either side of the subject were perceived to be displaced inwards (i.e. towards the subject). This tendency towards an inward displacement of the vanishing point is noticeably greater at outer probe sites. However, since a fixation cross was used to control eye and head movements, the judged displacement of vanishing points closest to the central position would be expected to be less, purely on the basis of improved localization directly in front of the subject.

If vanishing point eccentricity was the only factor that was operating, it is expected that the points in Figure 8 would be very similar across directions. This clearly is not the case. For the most part, displacements for Left-Right movement were displaced further to the right in relation to subjects location, than were corresponding displacements occurring when the sound moved in the opposite direction. This of course is the pattern one would expect, if the remembered vanishing points were displaced in the direction of the implied motion as predicted.

In order to evaluate the overall effect of speaker position and sound direction, subjects mean deviations at each probe location were treated by a within subjects, direction x location analysis of variance. While no main effect for sound direction was apparent, the location of the probe speakers, *F* (3, 42) = 60.064, $p < .0001$; and the interaction between speaker location and sound direction *F* (5, 62) = 13.346, $p < .0001$, were highly significant.

The effect of direction of implied motion on subjects' ability to localize the vanishing point was further explored by comparing the left to right, and right to left deviations at each of the 11 relative speaker locations. A student t-value was calculated for each comparison and the resultant values and associated probabilities are presented in Table 3.

Table 3: Student *t*-values based on a comparison between subject's mean deviations at each vanishing location, relative to sound direction.

Speaker Position	t-value	Probability
1	.69	.500
2	1.76	.103
3	1.20	.250
4	2.71	.018*
5	3.31	.006**
6	2.75	.016*
7	2.57	.023*
8	1.96	.072
9	0.17	.866
10	1.47	.163
11	2.50	.026*

* $p < .05$ - two tailed

** $p < .01$ - two tailed

Table 3 indicates that the perceived vanishing points differ reliably as a function of direction of motion, at the centrally located probe sites. It must also be noted that while speaker position 11 displayed a significant divergence of judgements, these were in fact in the direction opposite to that predicted. The speaker position seen to be of greatest relevance though, is the one positioned directly in front of subject (Position 6). At this point, one would anticipate localization accuracy to be at its best, since interaural temporal differences are zero. However, subjects, on average, judged the vanishing point of the sound to be to the right of this speaker for implied Left-Right motion, and to the left of it, when the sound moved in the opposite direction. This is as predicted by Freyd's (1984) movement induced memory displacement hypothesis.

While the above results would seem to provide considerable evidence in favour of a motion induced memory displacement effect, it needs to be remembered that identical speakers and the same absolute locations were **not** compared across directions, even though great care was taken to ensure that speakers were equivalent in loudness and timbre. The current procedures were adopted knowingly in the hope that long inducing sequences would maximize the likelihood of obtaining the predicted location displacement effects. Since the predicted effect was in evidence, it was decided to repeat the experiment with the subject seated in the centre of the 31 speaker array, for sequences inducing motion in either direction.

EXPERIMENT 4

SUBJECTS

Twenty two undergraduate students from the University of Canterbury served as subjects. The 15 female and 7 male subjects ranged in age from 19 - 31 years. Again, all indicated they were right-handed. None of these subjects had participated in the earlier research.

APPARATUS, STIMULI AND PROCEDURE

The design of the experiment was identical to that of Experiment 3, except that subjects were seated directly in front of the speaker No.16, located at the mid-point of the 31 speaker array.

The inducing sequences were reduced in length by three speakers (30 cms) so that the sound was relayed through a minimum of 11 speakers before it vanished.

The procedures followed in this equipment corresponded in every way to those of the previous study.

RESULTS AND DISCUSSION

Five subjects chose to eliminate up to two of their experimental responses after becoming distracted by extraneous sounds. The data rejected, were again shown to be distributed evenly across speaker locations. Head movements were monitored at random intervals, and none were observed. Subjects also reported no tendency to move their eyes from the fixation cross.

Treatment of the data followed that of the previous experiment. The raw subject data is displayed in Appendix C, Tables 5 & 6, while Figure 5 presents mean displacements as a function of direction of motion. It is important to draw attention to the fact that identical speakers and the same absolute locations are now being compared.

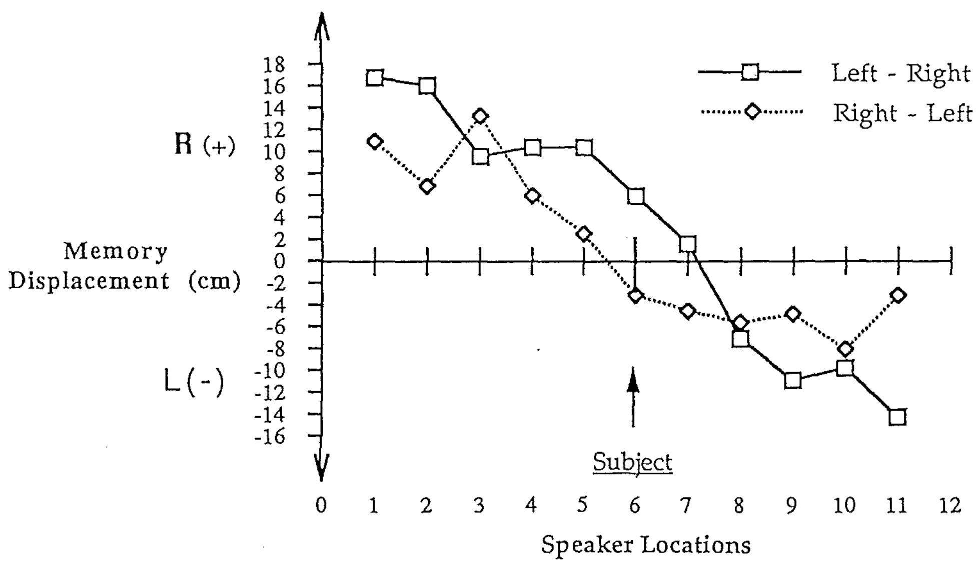

Figure 9: Experiment 4, mean deviations at each speaker position as a function of sound direction.

A pattern of results very similar to those of Experiment 3 is revealed. Again, regardless of the direction of the movement, vanishing points were perceived to be displaced inwards towards the subject, with this tendency being more pronounced for speakers of greater eccentricity.

Subject mean deviations at each speaker location were treated by a direction x location analysis of variance. The location main effect $F\ (3,\ 54) = 39.301$, $p < .0001$ was highly significant. While no main effect was observed for direction, the interaction between speaker location and sound direction $F\ (4,\ 92) = 9.402$, $p < .001$ was statistically significant.

To objectively determine the level of divergence of responses at each speaker, mean deviation scores from each subject were again compared across directions to yield a student *t*-value for each of the 11 speaker locations. Table 4 presents a summary of the values calculated for each comparison. This provides clear statistical evidence to show that the absolute locations at which subjects reported to the tone to vanish, varied according to direction at the three centre speakers. This would seem to provide strong evidence in favour of a motion induced memory displacement effect, since identical speakers and the same absolute location are being compared.

Table 4: Student t-values based on a comparison between subjects' mean deviations at each vanishing location, relative to sound direction.

SPEAKER LOCATION	t-VALUE	PROBABILITY
1	2.52	.020*
2	3.01	.007**
3	1.21	.238
4	1.60	.123
5	2.69	.014*
6	3.70	.001*
7	2.18	.040*
8	0.65	.522
9	1.98	.061
10	0.49	.625
11	3.18	.004**

* $p < .05$, 2-tailed

** $p < .01$, 2-tailed

Interestingly, there are also significant divergent effects shown at the outer speaker sites, with Figure 9 identifying a clear "cross-over" effect approximately two speakers each side of subject. It is difficult to offer an explanation for these effects other than to suggest that the inducing sequences are short at these points for one direction and long for the other. An alternative explanation is that there may be directional differences in attending to sounds, whereby subjects show either a right ear or left ear advantage. In fact the auditory literature supports such a speculation by providing some evidence to suggest a right hemisphere advantage (left ear) for the processing of non-verbal sounds. (Baddeley, 1976; Schiffman, 1982). If this is in fact the case, there may be a slight "attentional lag" before the subject can register the sound. Such a pattern seems suited to the data produced in this experiment, however no conclusions can be drawn without further experimentation.

Another striking feature to emerge from the results was the clear disparity in judgements for speakers immediately to the left and right of the subject (refer Figure 9). It was noted for that left to right movement, if the sound vanished at the speaker placed to the left of the subject, the judged vanishing point was displaced to the right of the vanishing point by a significant margin t (13) = 4.325, p < .001, 1-tailed. Yet, for right to left motion, judgements at this same speakerdid not differ signficantly from true vanishing point. Similarly, the speaker to the right of subject produced deviations which were significantly to the left of true vanishing point for right-left movement, t (13) = 2.011, p < .05, 1-tailed, yet deviations were not significantly different from zero when the sound appeared to move from left to right. A similar pattern to this was noted in Experiment 3, but no direct comparisons could be made since the actual speakers differed.

As these speakers were placed at an equal angular distance to each side of subject's midline, it is to be expected that judgements at these sites would be similar. However, the pattern of results quite clearly shows that subjects were able to locate the stopping position of the sound with good accuracy on the occasions where the sound was perceived as having just passed the body midline. The conclusions one can draw from this are not clear cut. It may well be, that a cognitive influence has infiltrated the hypothesised extrapolation tendency. If this were the case it would clearly deviate from Freyds claim (Finke & Freyd, 1985; Finke, Freyd & Shyi, 1986; Freyd, 1992) that mental extrapolations can not be halted instantly. However it is also possible that opposing influences could be operating. The tendency for subjects to displace sounds inwards was apparent at all locations, and this tendency would have the effect of negating the memory displacement effect as the sound moves away from the subject.

The sound localization literature attests to the fact that sizes in errors and response variability are smallest for stimuli directly in front of subjects, with a noticeable increase at more peripheral locations (Makous & Middlebrooks, 1990-cited in Middlebrooks & Green, 1991). Similarly, subjects have been shown to under-estimate distances when localizing a sound source (Handel, 1989) particularly when the sound is relatively close to them, since loudness differences seem to be the necessary cue. The inclusion of a control condition to assess localization ability when no movement is involved, is clearly needed. Unfortunately the need for static controls was not anticipated when the apparatus was built, and therefore a static localization task was not possible in the time available.

The results of this study are generally as predicted. They provide a convincing demonstration of a motion induced memory displacement effect by identifying a significant variation in the absolute position at which subjects indicate a tone to vanish as a function of a change in direction. The identification of a memory distortion for linear auditory apparent motion, also provides the catalyst for further research in this domain. Some ideas in this area will be explored in the final chapter.

CHAPTER 4

GENERAL DISCUSSION

Four experiments, aimed at the investigation of an auditory motion induced memory displacement effect, have been reported. Experiments 1 and 2, which adopted the representational momentum inducing techniques employed by Freyd & Finke (1984), failed to find any suggestion of a movement induced memory effect. However, two further experiments, modelled on Hubbard & Bharucha's (1988) apparent motion paradigm, provide strong evidence in favour of such a displacement.

An explanation for the failure of the first method to produce the predicted results, remains inconclusive. However, the inducing sequences were very short, spatial separation between speakers was perhaps excessive, and variability of the sequence direction and probe pitch, greatly increased task difficulty. Under such circumstances it is perhaps not surprising to discover a null effect, since Verfaillie & d'Ydewalle (1991), have argued that predictability appears to play a major role in the memory displacement effect. Ensuring a perfect match between the speakers used to probe the last remembered position, was also a problem.The slightest difference in timbre can create a uniquely characteristic sound, thereby making that speaker more easily identifiable. Concerns about the comparability of speakers was of no great consequence in the later two studies, as subjects physically identified the last heard location of the tone by directing a beam of light at the spot.

A major difference between the procedures though, related to the control that was exercised over the loudness cues in the initial two experiments. Since sounds are normally heard to increase in loudness on approach, the equation of the speakers in terms of intensity level, removed a major azimuthal localization cue. Whereas this may have lessened the perceptual experience of motion to some degree, a claim suggesting that it alone, could be responsible for the negative results, is dubious. The movement was implied rather than continuous, and the localization of a sound at the frequency level used in these experiments, is thought to be based primarily on interaural temporal differences, rather than intensive differences. Claims proposing that it was simply the loudness continuum creating the memory distortions in Experiments 3 &4, also cannot be substantiated. The task in question required subjects to select a spatial location to identify the vanishing position of the sound. If subjects had extrapolated the motion along the loudness continuum, they would clearly be unable to respond to a task requiring a locational judgement.

It is unfortunate though, that efforts to induce the memory effects have led away from the simple paradigm advocated by Freyd. By using apparent motion it could perhaps be asserted that subjects have experienced a sensory illusion of motion, rather than forming a cognitive representation of the movement, as is the case when separate discrete sounds are used. It could also be alleged that the perception of real motion could bias the results by producing auditory after-effects, which appear analogous to those found in vision. It seems that when a person is exposed to a moving source, they become adapted to the movement, and after the movement ceases there can be an apparent displacement in the direction opposite to that of the earlier motion (Perrott,1982). It will be recalled that a memory displacement effect opposite to that predicted by the momentum effect, was in fact noted in the last two experiments reported. This negative effect was evidenced at the final four speakers in each sequence, with the extent of negative displacement displaying a tendency to increase with length of inducing sequence. While it is unlikely that a negative after-image could account for the full extent of the negative shift noted in this experiment, some degree of bias from such an influence, must still be considered .

Such criticisms favour a repetition of a modified form of the standard implied paradigm employed in Experiments 1&2. Since the physical separation of the speakers (1 metre) may have broken down the cohesiveness of the event, the use of a greater number of speakers placed in closer proximity, with a slight decrease in the inter-stimulus interval, would be predicted to increase the perceptual salience of the situation. The response task was also seen to create confusion and add to the overall difficulty of the experimental situation. To simplify matters it may be more practical to use just one key which could be pressed when the subject detected a "match" to either a same or different judgement. In this way additional probe speakers could be incorporated into the procedure, and the percentages of either "sames" or "differents" could be compared across probe sites.

Just how people interpret auditory motion is still not clear. In the visual system there is a good deal of evidence for neural systems specialized for the detection of motion (e.g. Hubel & Weisel, 1962 cited in Schiffman,1982) but as yet, there is no compelling evidence for motion sensitive systems in the auditory system. It has been suggested that the nervous system may measure sound source location at two distinct times and then interpret a change in location as motion (Middlebrooks & Green, 1991). If people are capable of detecting auditory motion, they surely must have some sense of the rate or velocity of moving sources. For this reason it would be important to assess whether the memory shifts noted in the present study increase as implied velocity and acceleration are increased. This has been shown to be achieved quite simply, by altering the inter-stimulus intervals within the inducing sequence (cf. Finke, Freyd & Shyi, 1986). A more important aim though, would be to show that the induced memory displacement can be eliminated when the display sequence implies a deceleration of the sound movement to a final implied velocity of zero. In the context of this research, it is important to show that the forward memory displacements noted as the sound approached the subject, can be eliminated when the motion is presumed to have ceased.

While the literature asserts that accurate specification of sound source is better in the azimuthal compared to the vertical plane (Gatehouse, 1982) it would nevertheless be interesting to investigate memory displacement effects for vertical auditory movement. Since the localization of sound elevation is thought to rely upon spectral cues caused by the filtering effects of the pinna (Middlebrooks & Green.1991), there are no interaural temporal differences and thus no distinct left - right differences. For this reason, the assessment of the location and distance of a sound in the vertical plane has been referred to as "monaural localization". By using vertical sound motion, it will not only allow a comparison of directional influences, but it will provide the means of studying gravity effects (cf.Hubbard,1990). If a differential pattern of results can be found for sounds moving in a downward direction, compared to upward movement, this will provide more substantial evidence in favour of an abstract representational system. Such a prediction has already found support with the findings of Kelly & Freyd (1987), and Freyd,Kelly & DeKay (1990), who reported a velocity effect for auditory momentum. While the pitch of a tone is not normally considered to display momentum, it was suggested that there could in fact be an abstract connection between the two, by way of the Doppler Shift.

If representation is abstract, as Rhodes (1987) has attempted to show, then it may well be possible to combine both visual and auditory movement within the same inducing sequence. For instance, if subjects were presented with a sequence combining individual flashing lights, and a short auditory sequence, would it be feasible to expect a motion induced memory displacement?

Since auditory events in the real world overlap, the acoustic energy from one event may be masked or obliterated by other sounds. The perceptual system must therefore decide if the event has truly ceased or whether the noise has masked a continuing event. This is usually achieved by assessing the context of the situation, and applying our knowledge and expectations to the situation. This causes the listener to expect one signal and not another. Research has indicated that if a constant frequency is presented to a listener, and a silent interval is included, the listener hears a distinct gap. However, if a louder noise is inserted in place of the gap, listeners report hearing a continuous tone (Handel, 1989). It would appear that the identical tones on either side of the loud noise creates the expectation of a continuing event. By applying this knowledge to the procedures adopted in Experiments 3 & 4, it is argued that a "gap" in the inducing sound sequence, created by relaying a louder noise through 2-3 adjacent speakers, should have no effect on the memory displacement effect. If such an effect is affirmed, then a reliable control condition could be achieved simply by radically altering the tone that continued after this "gap". It seems clear that the perception of continuity depends upon the sounds on both sides of the interruption being the same. People cannot extrapolate the initial sound through the masking noise, but instead use use the sound on the other side to induce continuity. This being the case, it is argued that subjects will perceive a change in the sound as being a new event, and as such, no forward memory displacement effect should be apparent if subjects memory for the last position of a sound is probed shortly after the change.

It is hoped that this thesis, in providing strong evidence for the presence of a memory displacement effect in relation to the implied linear movement of a sound, will provide the foundation for continuing research in this area.

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APPENDICES

APPENDIX A - HANDOUTS

1. Consent Form

2. Subject Instructions
   Experiment 1

3. Subject Instructions
   Experiment 2

APPENDIX A: HANDOUT 1

UNIVERSITY OF CANTERBURY DEPARTMENT OF PSYCHOLOGY

CONSENT FORM

This research is being undertaken to fulfil the thesis requirement for an M.A. degree in Psychology. It involves an investigation of a person's memory for the location of sounds.

As a subject in this project you will be asked to listen to a sound that progressively moves from one position to another. At some stage during its progression the sound will stop abruptly. Your task will then be, to decide where the sound actually stopped.

All results will be recorded against a code number and each subject's pattern of results will remain totally confidential.

Participation in this research is entirely voluntary, and each subject will be required for 1 session only, lasting approximately 30-40 minutes.

CONSENT

SOUND LOCALIZATION STUDY

RESEARCHER: ANNE DELWYNEN

I agree to participate in the project described above, on the understanding that if at any time I wish to withdraw from the experiment, I may without prejudice, do so.

I understand that all information collected by me will be used in the above research only, and that the identity of all participants will remain confidential.

Name: ______________________

Signature:______________________ **Date:** ________________

APPENDIX A: HANDOUT 2

UNIVERSITY OF CANTERBURY DEPARTMENT OF PSYCHOLOGY

Researcher: Anne Delwynen

Telephone: 366 7001 Ext. 7190

Sound Location Study: Subject Instructions

Experiment 1

On each trial of this experiment you will hear a sequence of three brief sounds.

These will be followed by a fourth sound we call a **probe.** This probe will sound slightly different to the previous three sounds.

I would like you to concentrate very carefully on the progression of the first three sounds in each trial and to try to remember **exactly** where the third sound in the sequence **stops.**

When you hear the probe tone sound, I would like you to decide as quickly as you can, if that probe is coming from **exactly the same place** as the last sound in the sequence you heard; or whether it is somewhere to the **left** or to the **right** of the place you remembered.

On **one third of the trials** the probe will come from exactly the same place. On the remaining trials it will be displaced either to the right or left of the last sound, in equal proportions.

You will find that some of these judgements are relatively easy to make whilst others are very difficult.

On the bench in front of you are three keys. These are the keys you will use to record your decisions each time. At the start of each block of trials I would like you to position the index finger of your preferred hand lightly on the middle key.

I want you to press the key in the **middle** if you think the probe tone came from **exactly the same** place as the last tone in the sequence.

Press the **right key** if you think the probe tone is to right of the last tone you heard, and press the **left key** if you think the probe is actually to the left of the last tone in the sequence.

You may not find it at all easy to decide, but I want you to be as <u>accurate</u> as possible and also to decide as quickly as possible by pressing the appropriate key.

During the experiment I would like you to place the goggles you see in front of you, over your eyes. Position yourself comfortably at the back of the seat and direct your gaze straight in front of you.

Please try to keep your head as still as possible during each block of trials.

On the floor next to your foot you will find a small foot pedal. This is to be used to start the sound sequences at the beginning of each block of trials. Once you press the pedal there is a 1 second delay before the sounds start. You will use this pedal only six times during the entire experiment. I will advise you when it is required.

We will shortly be ready to begin the experimental session by having a short practice run (Demonstration Block) to allow you to familiarize yourself with the procedure and the equipment you will be using. It is important to emphasize however that the sounds in this demonstration will be presented much more slowly than they will be during the actual experimental stage. Feedback in regard to your performance will be provided in this block only.

Following on from this short initiation block will be two practice blocks consisting of 36 trials in each. During these blocks you will be using only two of the keys in front of you (i.e. Middle & Left or Middle & Right). This will provide you with practice at making the required discriminations using a simpler two-choice format, before you move on to the final three blocks which require the three key response.

If you do not have any questions we will shortly be ready to begin.

1. Please place the goggles over your eyes and position yourself in the required manner on the seat (i.e. rest yourself against the back of the seat and direct your eyes straight in front).

2. Place the index finger of your preferred hand gently on top of the middle key in front of you. (After making a key press response on each trial please return the index finger to this position each time.)

3. Remember to keep your head as still as possible during each block of trials.

4. When you are ready you may press the foot pedal to begin.

APPENDIX A: HANDOUT 3

UNIVERSITY OF CANTERBURY DEPARTMENT OF PSYCHOLOGY

Researcher: Anne Delwynen

Telephone: 366-7001 Ext. 7989

Sound Localization Study; Experiment No.2

GENERAL PROCEDURE:

On each trial of this experiment you will be aware of a sound travelling along behind the black curtain in front of you .

This sound will begin at either end of the black rod which you see mounted in front of the curtain. The starting point will be predetermined at the start of each block of trials, and this will remain constant throughout a complete experimental block. You will be fully aware of the sound's starting point before each block of trials commence.

Once this sound begins, it will move quite quickly towards the opposite end of the black rod. At some point it will abruptly stop.

I would like you to concentrate very carefully on the progression of this sound and try and pinpoint exactly the position at which it stopped.

APPARATUS:

LASER-POINTER - This is a simple pointer which is operated by depressing the grey button on the top. This emits a very small beam of light which you will use to identify where the sound has stopped after each trial.

WARNING: DO NOT POINT THIS TOWARDS YOUR EYES

FOOT PEDAL - On the floor in front of you is a foot pedal which will allow you to control the onset of each trial. When you are ready to begin each time, you just press the pedal and after a 1 sec. delay the sound will begin.

<u>SUBJECT INSTRUCTIONS</u>

1. I would like you to take a seat on this specially positioned stool. You will notice that in front of you there is a small white cross (+) painted on the black bar. During each trial I want you to focus your eyes on that cross.
   Once you press the foot pedal to start each trial your head must not move at all, and your eyes must remain fixated on that cross.

   <u>Please retain that position until the sound ceases.</u>

2. When the sound stops, I would like you to immediately point to the last place you heard the sound, using your laser pointer. To do this, just press the grey button, and focus the small beam of light onto the black bar at the required place. Please retain that position until the measuring instrument is in place and the result is recorded.

FEEL FREE TO MOVE YOUR HEAD AND EYES ONCE THE SOUND STOPS.

3. Each time when you are ready to begin a trial make sure that you are holding the laser pointer in your <u>right hand</u>. Next, press down on the foot pedal and focus your eyes and attention on the small cross in front of you. There will be a 1 sec. delay before the sound starts. Please remember to keep your head perfectly still and your eyes directed on the cross until the sound ceases. Try to direct your concentration on the exact position the sound stops at. It is now quite permissible for you to move your had and eyes to allow accurate identification of this spot.

4. After you have made a response on each trial, it is most important to re-focus your attention directly in front of you. Do not be influenced by the finishing point of the previous trial(s) as this may adversely affect your judgement in the following ones.

5. Since this task requires a high degree of attention over a reasonably long period, I realise it is easy to find oneself distracted on occasions. If you were <u>not</u> attending to a trial it is imperative that you inform me of this so I can delete that trial from the experiment. Failure to do so will seriously affect the accuracy of your results.

If you do not have any questions we will be ready to begin.

The experimental session will begin with a short practice block of 11 trials. This will allow you to familiarize yourself with the procedure and the equipment you will be using. Any further queries you may have can be answered after this practice.

Following on from this will be the actual experimental blocks, which consist of 33 trials in each. If possible, I would like you to complete two blocks of trials with the starting point of each block alternating between left and right. This will require a small adjustment to the position of your chair after each block. The entire session will take approximately 45 minutes.

APPENDIX B - EXPERIMENTAL SEQUENCES (EXP.1)

APPENDIX B: METHOD (Experiment 1 - Practice and Experimental Sequences

TABLE 1: Demonstration Block

	Speaker Locations	Probe Speaker	Condition	Key Press	Sound Direction
Trial 1	2-4-6	6	Same	Centre	←
Trial 2	6-4-2	1	Forward	Right	→
Trial 3	4-2-6	6	Backward	Right	←
Trial 4	1-2-5	6	Forward	Left	→
Trial 5	4-6-2	2	Same	Centre	←
Trial 6	4-2-1	2	Backward	Left	←

TABLE 2: Practice Block 1 (Right Practice)

	Speaker Locations	Probe Speaker	Condition	Sequence Type	Key Press	Sound Direction
Experimental Sequences	1-2-4	4	Same	Coherent	Middle	←
	1-2-4	3	Backward	Coherent	Right	←
	2-1-4	4	Same	Incoherent	Middle	←
	2-1-4	3	Backward	Incoherent	Right	←
Distractor Sequences	6-4-2	2	Same	Coherent	Middle	→
	6-4-2	1	Forward	Coherent	Right	→
	4-6-2	2	Same	Incoherent	Middle	→
	4-6-2	1	Forward	Incoherent	Right	→

TABLE 3: Practice Block 2 (Left Practice)

	Speaker Locations	Probe Speaker	Condition	Sequence Type	Key Press	Sound Direction
Experimental Sequences	1-2-4	4	Same	Coherent	Middle	←
	1-2-4	5	Forward	Coherent	Left	←
	2-1-4	4	Same	Incoherent	Middle	←
	2-1-4	5	Backward	Incoherent	Left	←
Distractor Sequences	6-4-2	2	Same	Coherent	Middle	→
	6-4-2	3	Backward	Coherent	Left	→
	4-6-2	2	Same	Incoherent	Middle	→
	4-6-2	3	Backward	Incoherent	Left	→

TABLE 4: Main Experimental Sequences

	Speaker Locations	Probe Speaker	Condition	Sequence Type	Key Press	Sound Direction
Experimental Sequences	1-2-4	3	Backward	Coherent	Right	←
	1-2-4	4	Same	Coherent	Middle	←
	1-2-4	5	Forward	Coherent	Left	←
	2-1-4	3	Backward	Incoherent	Right	←
	2-1-4	4	Same	Incoherent	Middle	←
	2-1-4	5	Forward	Incoherent	Left	←
Distractor Sequences	6-4-2	1	Forward	Coherent	Right	→
	6-4-2	2	Same	Coherent	Middle	→
	6-4-2	3	Backward	Coherent	Left	→
	4-6-2	1	Forward	Incoherent	Right	→
	4-6-2	2	Same	Incoherent	Middle	→
	4-6-2	3	Backward	Incoherent	Left	→

APPENDIX C - RESULTS

Table 1	Experiment 1	Raw Data
Table 2	Experiment 2	Raw Data
Tables 3 & 4	Experiment 3	Raw Data
Tables 5 & 6	Experiment 4	Raw Data

APPENDIX C - RESULTS (Table 1)

EXPERIMENT 1: Responses registered by each subject at the three probe locations

Subject No.	Sequence Type	BACKWARD PROBE			SAME PROBE			FORWARD PROBE		
		BWD	SAME	FWD	BWD	SAME	FWD	BWD	SAME	FWD
001	Coherent	17	1	0	4	14	0	0	17	1
	Incoherent	17	1	0	5	13	0	0	17	1
002	Coherent	12	6	1	7	9	2	4	8	6
	Incoherent	12	5	0	5	11	2	2	7	9
003	Coherent	16	2	0	0	14	4	0	7	11
	Incoherent	12	6	0	3	15	0	0	7	9
004	Coherent	15	3	0	14	4	0	8	10	0
	Incoherent	11	7	0	2	16	0	1	17	0
005	Coherent	15	3	0	3	14	1	0	0	18
	Incoherent	13	5	0	5	9	4	0	7	18
006	Coherent	9	7	2	2	14	2	4	13	1
	Incoherent	8	9	1	2	12	4	3	13	2
007	Coherent	8	5	5	2	11	5	0	5	13
	Incoherent	7	4	7	6	5	7	2	3	13
008	Coherent	14	4	0	4	9	5	1	2	15
	Incoherent	15	3	0	7	5	6	2	4	12
009	Coherent	3	12	3	4	10	4	1	10	7
	Incoherent	5	12	1	0	15	3	2	6	10
010	Coherent	16	2	0	6	10	2	0	11	7
	Incoherent	15	3	0	7	9	2	2	6	10

APPENDIX C - RESULTS (Table 2)

EXPERIMENT 2: Responses registered by each subject at the three probe locations

Subject No.	Sequence Type	BACKWARD PROBE			SAME PROBE			FORWARD PROBE		
		BWD	SAME	FWD	BWD	SAME	FWD	BWD	SAME	FWD
011	Coherent	5	12	1	0	18	0	0	10	8
	Incoherent	3	15	0	0	16	2	0	7	11
012	Coherent	5	11	2	1	11	6	1	8	9
	Incoherent	8	9	1	5	10	3	0	8	10
013	Coherent	3	12	3	0	15	3	0	10	8
	Incoherent	2	10	6	0	15	3	0	11	7
014	Coherent	11	3	4	4	5	9	7	4	7
	Incoherent	10	3	5	8	8	2	5	8	5
015	Coherent	6	10	2	2	6	10	3	3	12
	Incoherent	7	7	4	1	8	9	2	7	9
016	Coherent	5	7	6	1	9	8	1	6	11
	Incoherent	8	6	4	0	6	12	0	2	16
017	Coherent	14	4	0	4	13	1	0	14	4
	Incoherent	6	12	0	1	15	2	0	10	8
018	Coherent	4	11	3	2	5	11	3	3	12
	Incoherent	1	9	8	1	9	8	0	2	16
019	Coherent	7	11	0	4	10	4	3	2	13
	Incoherent	4	14	0	1	10	7	0	5	13
020	Coherent	3	8	7	4	9	6	0	7	11
	Incoherent	2	10	6	3	10	6	1	4	13

APPENDIX C: RESULTS

Table 3: Experiment 3. (Left - Right Tonal Progression).
Each subject's mean localization accuracy reported as a deviation from zero[1] (true position). Positive numbers indicate an error in the direction of movement, while negative numbers show an under-estimation of true location.[2]

	Condition Numbers										
Subject	1	2	3	4	5	6	7	8	9	10	11
1	1.19	.43	-.15	.19	.24	.08	-.79	-.60	-1.02	-2.27	-2.73
2	3.06	3.30	2.00	1.35	.83	-.12	-.82	-1.07	-1.66	-2.26	-2.02
3	3.35	3.63	2.20	1.63	2.08	1.23	.78	1.04	.04	-.94	-.91
4	2.26	2.10	1.56	1.25	1.06	.05	-.56	-.72	-2.11	-3.34	-3.04
5	3.23	2.41	2.65	2.45	1.88	1.56	1.53	1.08	.55	-.22	-.67
6	.80	2.41	2.31	1.14	.85	1.58	1.10	.78	-.16	-1.21	-1.96
7	1.40	2.43	1.23	1.00	-.41	-.31	-.80	-1.74	-1.87	-2.47	-2.31
8	.79	.48	.54	.34	.43	-.07	.68	.59	-1.06	-1.61	-2.79
9	1.21	1.18	1.30	.59	.43	.33	-.57	-.97	-1.74	-2.54	-2.59
10	.84	.70	.88	.71	.69	-.17	-.41	-.54	-1.09	-1.96	-.99
11	1.66	1.16	.21	1.10	1.85	1.91	.33	-.64	-1.16	-.55	-.61
12	3.00	2.36	3.56	2.50	1.86	1.06	.53	1.93	.96	.06	-1.52
13	2.35	2.11	1.50	1.10	2.31	.85	.93	-.59	-.49	-.94	-1.64
14	1.91	1.43	.89	.78	-.11	-.29	-.16	-1.27	-2.16	-2.47	-3.14
	14	15	16	17	18	19	20	21	22	23	24
	Actual Speakers										

Note: [1] To convert to centimetres, multiply by 10.
[2] To compare actual speakers, Condition number 1 (Left to Right) was matched with Condition 11 (Right to Left)

Table 4: Experiment 3. (Right to Left Tonal Progression). Each subject's mean localization judgement reported as a deviation from zero (true position). Positive numbers indicate an error in the direction of movement, while negative numbers show an under-estimation of the true position.

	Condition Numbers										
Subject	1	2	3	4	5	6	7	8	9	10	11
1	.36	.40	1.15	1.48	1.63	1.05	.75	.58	.39	-.29	-.09
2	1.20	2.10	1.33	1.69	2.16	1.83	1.33	-.67	.33	-.37	-2.04
3	4.69	4.13	3.46	3.56	2.85	3.28	1.80	1.55	1.21	.83	.66
4	.91	2.78	2.45	1.66	1.15	.49	-.02	-.67	1.59	-.96	-1.42
5	.06	.48	.63	1.13	-.10	-.79	-.67	-2.01	-2.46	-3.09	-3.56
6	-.09	.50	-.14	-1.19	-.67	-.39	-59	.63	-.84	-1.22	-2.11
7	.76	-1.06	.90	1.23	.50	.39	0	-.47	-1.37	-1.17	-2.27
8	.36	.16	.95	2.06	.95	2.41	3.11	1.76	.43	.46	1.13
9	-2.29	0	.33	.95	.25	-.41	-.76	-1.07	-2.07	-2.66	-3.44
10	-.04	1.01	1.48	.79	1.10	-.11	-1.09	-.36	-1.61	-1.19	-1.34
11	.11	.31	.33	.44	.46	-.09	.75	-.74	-1.47	-1.91	-1.51
12	2.56	2.46	2.00	1.93	.83	.69	-.14	-.10	-.97	-.24	-.67
13	-.89	-1.31	-1.92	-.72	-2.39	-1.87	-1.51	-2.47	-2.86	-2.47	-3.96
14	.06	.56	1.05	.68	.71	.16	-.42	-.19	-1.02	-1.26	-2.04
	20	19	18	17	16	15	14	13	12	11	10
	Actual Speakers										

Table 5: Experiment 4. (Left to Right Sound Progression). Mean localization judgement reported by each subject across all probe locations.

	Condition Numbers										
Subject	1	2	3	4	5	6	7	8	9	10	11
1	2.56	-.51	-.19	-.42	-.15	-1.32	-.64	-1.36	-1.02	-1.17	-1.46
2	.36	1.23	-.97	.91	.46	.53	-.09	-.85	-.92	-1.45	-1.64
3	1.63	2.31	2.30	1.83	2.26	1.50	-.02	.05	-.91	-.32	-.94
4	-.31	-1.04	-2.01	.06	-.25	.34	1.21	.53	.12	.28	-.69
5	1.44	1.13	.60	.16	1.46	.26	.50	-.59	-.24	-.09	-.97
6	1.75	2.30	1.25	.83	-.02	-.11	-.70	-2.26	-2.82	-3.22	-4.49
7	.35	-.36	-1.07	-.09	-.04	.03	-1.22	-1.61	-1.87	-1.96	-2.49
8	3.53	3.60	3.16	3.53	2.56	1.09	.98	-.77	-.61	-1.09	-1.06
9	.75	2.05	.48	2.25	1.40	1.68	.14	-.02	-.71	-.80	-1.34
10	1.91	.46	.98	-.04	-.85	.79	-.14	-2.02	-2.21	-2.37	-2.59
11	2.63	2.23	1.79	2.33	2.98	1.0	.73	.28	.09	.40	-.09
12	2.95	2.83	2.25	1.95	1.25	1.53	.31	-.67	-1.42	.11	-.04
13	1.65	2.16	1.71	1.73	1.71	.44	-.34	-1.76	-1.79	-.75	-.84
14	2.00	2.28	1.88	.69	1.61	.19	-.37	-1.20	-1.82	-2.42	-2.27
15	-1.27	-.52	-1.45	-2.51	.46	1.24	.19	-.91	-1.92	.33	-.46
16	2.31	2.65	1.20	1.48	1.13	.76	.68	-.52	-.29	-1.12	-1.50
17	.98	.26	1.33	1.01	.49	1.11	-.52	-.61	-.94	0	-.49
18	2.63	2.83	2.21	1.48	.70	-.39	-.69	-1.64	-1.86	-2.92	-3.51
19	4.88	4.78	3.55	3.83	3.48	2.06	2.80	3.0	1.88	1.41	1.83
20	2.28	1.88	.58	1.01	.53	-.09	.38	-1.39	-1.89	-1.62	-2.17
21	.40	.70	.11	-.41	.73	-.07	-.62	-1.20	-2.17	-2.14	-3.56
22	1.38	1.75	1.20	1.10	.81	.43	.78	-.21	-.77	-.71	-.76
	11	12	13	14	15	16	17	18	19	20	21
	Actual Speakers										

Table 6: Experiment 4. (Right to Left Tonal Progression). Mean localization judgement reported by each subject across all probe locations.

	Condition Numbers										
Subject	1	2	3	4	5	6	7	8	9	10	11
1	-1.72	-.82	-.56	-.97	-.67	.46	-1.67	-.72	-1.64	.16	-.52
2	-.89	-1.72	-1.55	-.19	-.62	-1.52	-1.70	-1.77	-1.62	-1.06	-.34
3	-1.19	.25	-3.14	-.44	-.51	.43	-.50	-.56	-1.49	-.76	-1.12
4	1.16	1.55	.85	1.30	1.26	.10	-.78	-.11	-.42	-1.12	-.36
5	.81	.39	.81	.15	-.04	-.52	.31	-.66	-1.29	-1.49	-2.16
6	1.46	1.25	2.43	1.61	.98	.60	.66	-.15	-1.02	.78	-.46
7	1.16	1.85	1.23	1.78	.14	-.39	-.52	-.82	-.97	.25	-.20
8	.58	1.30	-.46	1.58	1.48	1.28	.61	-.02	-1.94	-2.56	-2.04
9	1.0	2.28	1.86	1.11	.86	.84	-.39	-.94	-2.22	-2.57	-2.89
10	.96	.01	1.68	1.88	.84	-.09	.13	-.47	-1.54	-.94	-1.52
11	.91	.71	.74	.81	.90	1.01	.10	-1.07	-.57	-1.31	-1.14
12	-1.17	-.62	.46	1.08	.76	-.05	-.69	-1.70	-1.20	-1.24	-1.89
13	.70	.96	1.36	1.33	1.20	.40	-.11	-.05	-1.81	-.93	-1.37
14	1.20	1.76	.75	-.02	.55	.33	.28	.28	-1.02	.43	-.49
15	-.30	.70	-.55	-.24	.69	2.25	1.90	1.20	.17	.98	.86
16	-.51	-1.09	.16	.26	-.70	.10	-.35	-.44	-1.24	-1.67	-1.59
17	1.28	2.08	.83	.15	-.05	.15	.44	-.77	-.17	.93	.20
18	2.46	2.28	2.03	1.23	.99	.13	-.46	-.75	-1.66	-.92	-2.14
19	1.28	1.75	.73	-.84	.70	-.24	1.34	-.77	-1.59	-1.49	-2.72
20	.83	2.10	1.33	1.11	.93	.25	-.22	-.32	-.89	-.56	-1.12
21	-.67	.50	.43	.48	-.97	.43	-1.07	-.56	-2.64	-1.39	-1.41
22	2.17	.41	-.59	-.61	1.48	1.03	-.07	-1.84	-2.09	1.58	.58
	21	20	19	18	17	16	15	14	13	12	11

Actual Speakers

TABLE 7: ANOVA Summary Table for Experiment 3

Source of Variation	df*	Sum of Squares	Mean Square	F	p	Epsilon Correction
Subjects	13	116.518	8.963			
D	1	12.224	12.224	1.175	.2981	
Error	13	135.280	10.406			1.00
L	10	334.760	33.476	60.064	.000	
Error	130	72.454	.557			.32
DL	10	44.970	4.970	13.346	.000	
Error	130	43.806	.337			.48

TABLE 8: ANOVA Summary Table for Experiment 4

Source of Variation	df*	Sum of Squares	Mean Square	F	p	Epsilon Correction
Subjects	21	156.584	7.456			
D	1	3.497	3.497	.753	.3954	
Error	21	97.561	4.646			1.00
L	10	346.681	34.668	39.301	.000	
Error	210	185.245	.882			.26
DL	10	51.177	5.118	9.402	.000	
Error	210	114.309	.544			.44

* Conservative degrees of freedom, being the nearest integer following multiplication by Epsilson Correction, were used to account for deviance of data from assumptions underlying within - subjects Analysis of Variance.